THE LOOSE LEAF LABORATORY MANUAL

THE WILEY TECHNICAL SERIES
J. M. JAMESON, *Editor*

ELEMENTARY ELECTRICAL TESTING

BY

V. KARAPETOFF
Cornell University

A MANUAL FOR TECHNICAL HIGH SCHOOLS AND FOR EVENING CLASSES IN APPLIED ELECTRICITY AND ELECTRICAL MACHINERY

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ELECTRICAL TESTING

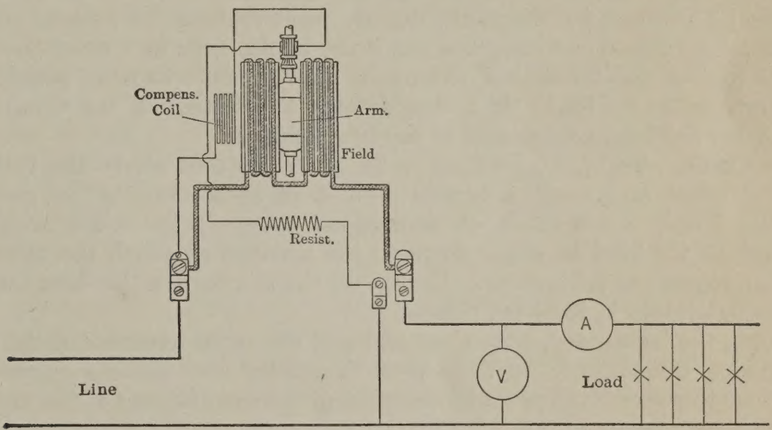
EXPERIMENT E 200–1. CALIBRATION OF A COMMUTATOR-TYPE WATT-HOUR METER WITH DIRECT CURRENT

Apparatus.—Watt-hour meter; ammeter; voltmeter; stop-watch; load rheostat.

Note.—An indicating wattmeter, if available, is preferable to an ammeter and a voltmeter.

The purpose of the experiment is: (*a*) to adjust the brake magnets so that the meter reads correctly at the rated load; (*b*) to adjust the friction compensation in such a way that the meter starts on as small a load as possible, without danger of creeping at no load; (*c*) to obtain a calibration curve (with the best possible adjustments) showing the per cent of error at various loads.

Connections.—The connections for the calibration are shown in the diagram; if an indicating wattmeter is used, its series coil is connected in place of the ammeter, and the shunt coil in place



Connections for Calibrating a Watt-hour Meter.

of the voltmeter. On small loads the power consumed in the voltmeter or in the shunt coil of the wattmeter may be appreciable, and may have to be added to the load. If the voltage is e, this loss is $i^2r = e^2/r$, where r is the resistance of the shunt circuit.

Data Sheet.—The tabular record of data must contain columns marked seconds, revolutions, volts, and amperes (or watts).

The Gear Ratio.—The reduction ratio of the gears between the meter shaft and the lowest recording dial is usually known. If not, it can be determined by a preliminary run, counting the number of revolutions of the disk necessary to move the lowest dial one division. This ratio is usually an even number such as 100, 200, etc. To save time, this test ought to be made on a heavy overload and possibly with one or more brake magnets removed, so as to run the meter as fast as possible.

Full-load Adjustment.—Adjust the load rheostat so as to obtain a load nearly equal to the rated load of the meter. Keep the load constant, and count the number of revolutions of the armature shaft during a minute or so (use a stop-watch). Knowing the gear ratio, the error of the meter may be calculated.

Suppose, for instance, that a constant load of 180 kw. was put on an integrating wattmeter and kept constant by means of an indicating wattmeter. Suppose that 15 revolutions of the armature disk be counted during 28 seconds, and that the reduction ratio of the recording gear be $1000 \div 1$. If the value of one complete revolution of the pointer on the lowest dial is 100 kw.-hr.,

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the armature disk must complete one revolution while 100÷1000 kw.-hrs., or 0.1 kw.-hr. is delivered to the load circuit. During the test, an energy equal to 180×28 kw.-sec., or

$$180 \times \frac{28}{3600} = 1.4 \text{ kw.-hrs.},$$

has been delivered to the circuit. Therefore, the disk should have completed

$$1.4 \div 0.1 = 14 \text{ revolutions.}$$

In reality it made 15 revolutions; thus, at this particular load the meter runs about 7.1 per cent fast, and consequently registers 7.1 per cent more energy than is actually consumed.

Adjust the brake magnets so as to obtain a more nearly correct speed, and repeat the run. After a few trials the adjustment can be made nearly perfect.

Adjustment of the Friction Compensating Coil.—In some meters the adjustment is made by moving the coil, in others by regulating the current through the coil. Adjust the meter so that the armature is ready to start on a very light load, but there is no danger of its creeping at no load. Sometimes a meter, correctly adjusted on a testing rack, begins to creep at no load, when put in service on a wall where it is subjected to jarring from the street or from an engine working near by. Therefore, jar the meter slightly while making the no-load adjustment, Also, try throwing off a heavy load suddenly and see if the meter stops in a short time. Determine at what lowest per cent of the rated load the meter can be made to start positively, without the danger of its creeping at no load. If a considerable adjustment of the compensating coil was necessary, check the full-load adjustment of the brake magnets.

Calibration Curve.—Bring the load up to 25 to 50 per cent above the rating of the meter. Keep the load constant and count a certain number of revolutions of the meter shaft, with a stop-watch. The larger the number of revolutions counted, the more accurate will be the calibration. Reduce the load in steps, down to the smallest at which the meter runs positively and, at each step, repeat the calibration. Record all the readings in the data sheet. The calibration curve ought to contain at least ten points.

Before leaving the laboratory, note the make and the serial numbers of the instruments used and their correction constants if any. Inspect the meter and make a sketch of its principal parts. Make clear to yourself the precautions taken in the construction of the case so as to prevent tampering by dishonest persons.

Report.—(1) Describe the meter tested and illustrate your description by neat sketches of details.

(2) Give your calculations for full-load adjustment.

(3) Describe your findings with regard to the light-load adjustment.

(4) Plot the calibration curve, using per cent of rated load as abscissæ and per cent "slow" or "fast" as ordinates.

(5) Answer the following questions:

(*a*) Is the calibration of the meter affected by reasonable fluctuations of voltage?

(*b*) What is the higher limit of voltage on which a given meter may be operated with safety?

(*c*) Will the meter run backwards if the line wires are interchanged?

(*d*) If there is a suspicion that a dishonest customer tries to cheat the power supply company by tampering with the meter, how would you proceed in detecting and proving his guilt?

(*e*) A meter is designed for 20 amp. current and has 8 turns in the series coils. How would you redesign the meter for 40 amp. capacity at the same voltage, without changing the armature or the gears?

THE LOOSE LEAF LABORATORY

ELECTRICAL TESTING

EXPERIMENT E 201–1. MAGNETIZATION CURVES IN IRON AND STEEL. HYSTERESIS LOOP

Apparatus.—Specimens of cast iron, electrical steel laminations, wrought iron, etc., in the form of rings provided with primary and secondary windings; ammeter; ballistic galvanometer; resistance box; adjustable rheostat; storage battery; double-pole, double-throw switch; fuse block.

The purpose of the experiment is to obtain magnetization or **B-H** curves of the available specimens, the curves to be similar to the curve shown in Fig. 1. This curve gives the relation between the magnetic intensity, **H**, and the flux density, **B**, in the specimen. The magnetic intensity is to be expressed in ampere-turns per cm. length of path, and the flux density in gausses. Steel and iron retain some magnetization after the external magnetomotive force has been removed; for this reason the magnetization curve depends upon the preceding "history" of the sample. When all traces of this history or "residual magnetism" have been removed, the magnetization curve begins at the origin, or $\mathbf{B}=0$ for $\mathbf{H}=0$. This curve, OM, Fig. 1 is called the neutral or the virgin curve of the material.

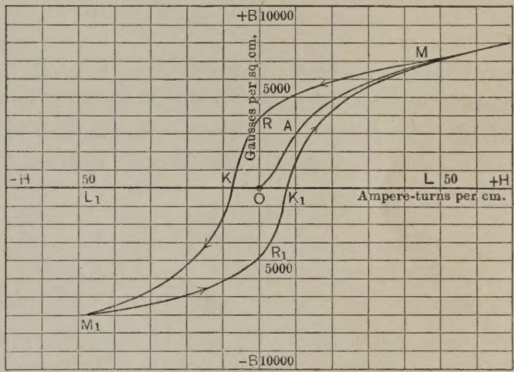

Fig. 1.—Magnetization Curve and Hysteresis Loop.

If, having reached a point M on the neutral curve ($OL=50$ ampere-turns per cm.), the current in the exciting winding be reduced, the values of **B** do not follow the curve MO, but follow the curve MR. When the exciting circuit is opened, the sample still possesses a flux of a density of about 4000 gausses. If now the exciting magnetomotive force be reversed, it takes between 7 and 8 ampere-turns per cm. to remove the residual magnetism. Increasing the magnetizing force in the negative direction to the value $OL_1=50$ ampere-turns per cm., the point M_1 is reached, for which the flux density $L_1M_1=LM=7000$ gausses. If now the current be again reduced to zero and then increased in the opposite direction, the flux density follows the curve $M_1R_1K_1M$, thus completing the "hysteresis loop." For each point on the neutral curve there is a corresponding hysteresis loop similar to the above.

The Ballistic Galvanometer.—A ballistic galvanometer is an instrument which, by its

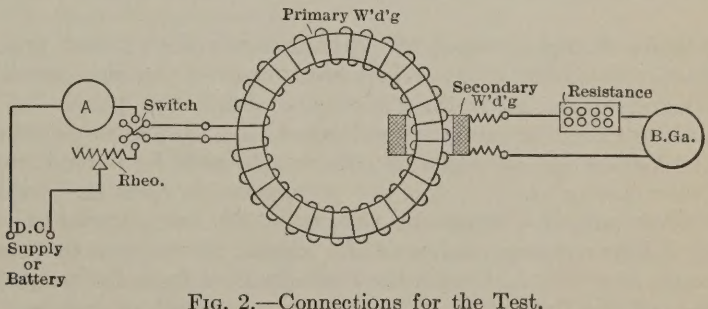

Fig. 2.—Connections for the Test.

deflection, measures a rapid electric discharge passed through its moving coil. Referring to the diagram of connections, Fig. 2, if the value of the flux in the specimen be quickly changed

by changing the resistance in the battery circuit, an electromotive force of short duration is induced in the secondary winding connected to the galvanometer. This electromotive force produces a "transient" current in the secondary circuit, so that there is a brief electric discharge through the galvanometer. Thus, a ballistic galvanometer may be made to measure variations in electric flux, utilizing the law of induction.

Theory and experiment show that the deflection on the discharge is proportional to the change in flux. Moreover, with the same e.m.f. the instantaneous current is inversely proportional to the resistance of the secondary circuit (Ohm's law), so that the total discharge is also inversely proportional to the total resistance of the galvanometer circuit (including the secondary winding, the resistance box and the resistance of the galvanometer coil). The induced e.m.f., and consequently the discharge, is proportional to the number of turns in the secondary winding. We thus have

$$\text{Discharge } Q=\frac{C_1 n\Phi}{R}, \qquad \text{(1)}$$

where Φ is the *sudden change in flux*, n is the number of turns in the secondary winding, R is the resistance of the secondary circuit, and C_1 is a coefficient of proportionality. But, on the other hand, the discharge Q is also proportional to the deflection δ as read on the scale, or $Q=C_2\delta$, where C_2 is a constant. Eliminating Q from the two equations, and solving for Φ we get

$$\Phi=\frac{\delta R}{Cn}, \qquad \text{(2)}$$

where C is equal to C_1/C_2 and is the galvanometer constant for flux. The constant C is either given, or may easily be determined by producing a known variation of flux, Φ, through a coil connected to the galvanometer as explained under "Calibration of the Galvanometer."

Method.—Connect the apparatus as in Fig. 2. The neutral curve and the hysteresis loop are obtained by varying the flux in steps. That is, beginning at the point O of the curve, the magnetomotive force is suddenly raised by a known amount, and the discharge through the galvanometer is observed. The flux Φ_1 is calculated by using formula (2). Let now the current be again increased by a certain amount and the discharge observed. Let the new flux variation be Φ_2. Then the total flux in the sample is $\Phi_1+\Phi_2$. Thus, by continuing this process in steps the magnetization may be carried to any desired point M.

Starting now on the hysteresis loop, the current is reduced, so that the galvanometer deflects in the opposite direction, and the new values of Φ are to be subtracted from the preceding sum. The purpose of the preliminary trials is to decide on the number and the approximate size of the steps in which the current is to be varied, to select the proper value of the resistance in the galvanometer circuit, and to acquire some skill in the handling and reading of the ballistic galvanometer.

To Demagnetize the Sample.—Open the galvanometer circuit and bring the magnetizing current to the highest practicable value. Now keep on reversing the current by means of the double-throw switch and at the same time gradually reduce the current to zero by means of the rheostat. If this operation is carefully performed, the sample is practically neutral. The student must now be careful not to magnetize the sample until he is ready to begin the neutral curve. Moreover, once having started, it is not permissible to open the circuit or to reduce the current until the desired limit M is reached. Otherwise, the sample would be started on another hysteresis loop, and all the preceding readings lost. Should this happen by oversight, demagnetize the sample by reversals as above, and begin the readings anew from the point O.

The Test Proper and the Data Sheet.—The test is conducted as explained in the preliminary trials, keeping in mind the precautions stated in the preceding paragraph. Record the amperes and the galvanometer throws, beginning with the point O and taking a complete hysteresis loop. Also note the values of the resistance plugged in the galvanometer circuit.

Perform similar tests with the other kinds of steel and iron available, using the same maximum value of **H** in all cases. Be careful to mark the readings which are negative.

Before leaving the room, note the following data: The galvanometer constant, the number of turns in the primary and the secondary windings on the rings, the cross-section of the iron and the mean length of the path of the flux in the rings.

Calibration of the Ballistic Galvanometer.—If the galvanometer constant C is not known, remove the specimen ring, and connect in its place the primary winding of a *standardizing solenoid* with an air core. This is a straight solenoid, the axial length of which is large as compared to the diameter of the air core. When such a solenoid is energized, the magnetic flux density inside it, near the middle portion, varies according to the theoretical relation

$$\mathbf{B}_a = 1.26\ \mathbf{H}_a, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where $\mathbf{B}_a$ is in gausses, and $\mathbf{H}_a = n_1 i$, is the magnetic intensity in ampere-turns per centimeter length. In this expression i is the current in amperes and n_1 is the number of primary turns per centimeter length. Knowing $\mathbf{B}_a$ and the cross-section A of the air core in square centimeters, the flux inside the solenoid is determined from the formula

$$\Phi_a = \mathbf{B}_a A \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Thus, in order to find the constant C of the galvanometer, place a secondary winding of a known number of turns over the middle portion of the standardizing solenoid and connect this secondary winding to the ballistic galvanometer. Bring up the current to a desired value (with the galvanometer circuit open), close the galvanometer circuit and open the primary circuit. Note the deflection of the galvanometer, the value of the primary current, and the resistance of the secondary circuit. Also determine the values of n_1 and A for the solenoid. With these data, using equations (3) and (4), the flux Φ_a becomes known, and consequently C can be calculated from equation (2). It is advisable to take several readings, using different values of current so as to eliminate possible errors of observation, and to increase the accuracy of the result.

Report.—(1) Plot **B–H** curves on one and the same sheet of cross-section paper, and to the same scale, so as to bring out clearly the difference in the properties of the samples investigated.

(2) On the same sheet plot equation (3) for the air, so as to show how much more "permeable" iron is than the air.

(3) For at least one sample, plot a curve of *relative permeability* against values of **B** in iron as abscissæ. Relative permeability is defined as

$$\mu_r = \frac{\mathbf{B}}{\mathbf{B}_a};$$

in other words, it is the ratio of flux density in iron to that in the air, for the same value of **H**. Use values of **B** from the neutral curve.

(4) If you had to determine your own galvanometer constant, give the data and show how you found the result.

(5) Answer the following questions:

(*a*) What would be the shape of the magnetization curve and of the hysteresis loop if the sample were not thoroughly demagnetized at the beginning of the test?

(*b*) What would be the shape of these curves if during the test the current were reduced and then increased again, due to a wrong manipulation?

(*c*) Why does the ballistic galvanometer give wrong indications when the flux varies slowly instead of suddenly?

(*d*) Explain why if the rings were not uniformly wound but the primary winding were concentrated at one place of the ring, an error would be introduced due to magnetic leakage through air.

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EXPERIMENT E 201–2. INFLUENCE OF AIR-GAP IN A MAGNETIC CIRCUIT

Apparatus.—A magnetic circuit with adjustable air-gaps, such for example, as that shown in Figs. 1 and 2; exciting coils for the same; a secondary coil for the same; ammeter; ballistic galvanometer with a resistance box (multiplier); rheostat for the exciting circuit; double-pole double-throw switch; fuses.

The purpose of the experiment is to investigate the harmful effect of an air-gap in a magnetic circuit which consists largely of iron. The presence of an air-gap reduces considerably the flux with a given magnetomotive force; much more excitation is required, therefore, in order to obtain the same flux as without the air-gap. For this reason, in electrical machinery and apparatus, air-gaps are avoided or their length is reduced to a possible minimum. This experiment must be preceded by Experiment E 201–1 on "Magnetization Curves in Iron," and the student is assumed to be familiar with the method and the explanations given there.

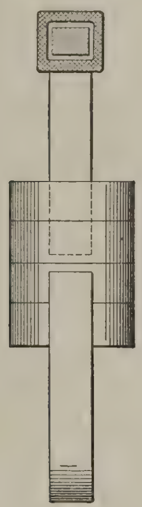

Fig. 1.—Magnetic Circuit with Adjustable Air-gap.

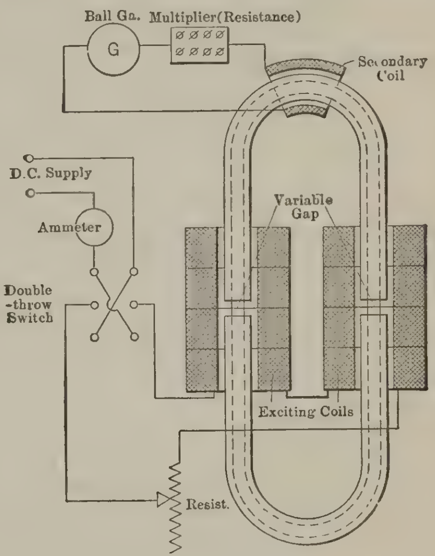

Fig. 2.—Diagram of Connections.

Connections.—The diagram of the required connections is shown in Fig. 2. The exciting coils are concentrated symmetrically near the air-gap, so as to avoid magnetic leakage which would vitiate the results.

Data Sheet.—Record the exciting amperes, galvanometer deflections, the resistance in the galvanometer circuit, and the length of the air-gaps.

Readings.—Take magnetization curves of the apparatus with various known values of the air-gap. Before beginning the first run, make a few preliminary trials so as to select proper values of the steps in changing the current and of the resistance in the galvanometer circuit. If desired, the method of reversals may be used instead of that of increasing the current step by step. Beginning with zero current, increase the current to say 2 amp. by closing the switch with the proper resistance in the exciting circuit, and read the galvanometer deflection. Now open the galvanometer circuit and slowly increase the current to say 3 amp. Close the galvanometer circuit and quickly reverse the double-throw switch. The flux is changed from $+\Phi$ to $-\Phi$, so that the change in flux is 2Φ. This value must be used in formula (2), Experiment E 201–1.

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Now raise the current to say 4 amp., and again reverse rapidly. With this method, twice the total flux is measured in each case, and not the additional flux as in the step-by-step method. When the galvanometer deflections increase beyond the limit of the scale, more resistance is to be connected in the galvanometer circuit, so as to reduce the sensitiveness of the instrument.

(*a*) After the preliminary trials eliminate the air-gaps as much as possible by bringing the iron cores together, and demagnetize the iron cores thoroughly. Take a magnetization curve and again demagnetize the circuit.

(*b*) Repeat the test with a very small but definite air-gap, say 0.2 mm. Such an air-gap is obtained by interposing a piece of paper of fiber between the iron cores; these materials being non-magnetic have the same effect as so much air.

(*c*) Make similar tests with larger air-gaps.

Before leaving the room, measure the dimensions of the cores, ask about the number of turns in the coils, find out the galvanometer constant, and the correction of the ammeter if any.

Report.—(1) Plot curves of flux against exciting ampere-turns, one curve for each value of the air-gaps.

(2) Plot curves of flux densities against the ampere-turns required for the air-gaps alone. This is done by subtracting from the total ampere-turns those required for the iron parts. For instance, let 200 ampere-turns be required for a total flux of say 30,000 lines when the air-gap is 0.5 mm., and 40 amp.-turns for the same flux with no air-gap. Then $200-40=160$ amp.-turns are required for the air-gaps. Theoretically these curves are straight lines and must show that the air-gap ampere-turns are proportional to the length of the gap and to the flux density. Check this relation and explain the sources of discrepancy and inaccuracies if any.

(3) Check equation (3), given in Experiment E 201–1, "Magnetization Curves," as follows: Let the air-gaps in one of the tests be 0.4 mm. each, or together 0.8 mm. At a flux density of say 3000, the intensity in the air-gaps is $\mathbf{H}_a=3000/1.26=2390$ amp.-turns per cm. Hence, the ampere-turns required for the two air-gaps are $2390\times0.08=191$. From your curves you should find approximately this value. Check this relation, for several of your curves, and explain any possible sources of discrepancy.

EXPERIMENT E 201–3. INFLUENCE OF THE LENGTH AND CROSS-SECTION OF THE MAGNETIC CIRCUIT ON ITS RELUCTANCE

Apparatus.—Four or six U-shaped rectangular iron cores similar to those shown in the sketch below; the same number of straight pieces of the same cross-section that may be put between the abutting ends of the U-pieces; exciting coils; secondary coils; ammeter; ballistic galvanometer with a resistance box (multiplier); rheostat for the exciting circuit; double-pole, double-throw switch; fuses.

The purpose of the experiment is to prove that the number of ampere-turns required to produce a certain flux is proportional to the length of a uniform magnetic circuit; also to show that the same number of exciting ampere-turns can be made to produce a much larger flux by increasing the cross-section of the magnetic circuit. This experiment must be preceded by E 201–1, "Magnetization Curves in Iron," and the student is assumed to be familiar with the method and the explanations given in that exercise.

Connections.—A diagram of connections for the experiment is shown in Fig. 2. The

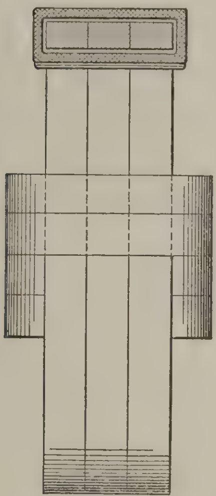

Fig. 1.—Adjustable Magnetic Circuit.

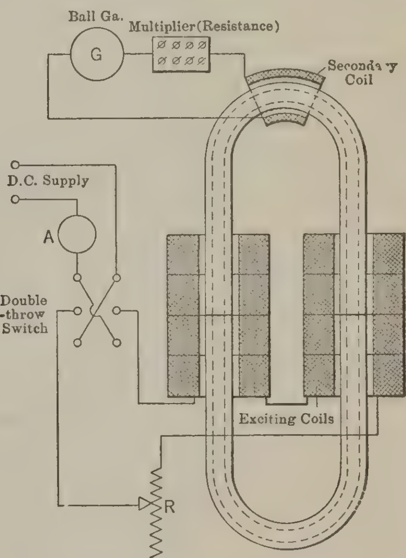

Fig. 2.—Diagram of Connections.

exciting coils must be distributed as nearly as possible over the length of the circuit so as to avoid magnetic leakage which would vitiate the results.

Data Sheet.—Record exciting amperes, galvanometer deflections and the resistance in the galvanometer circuit. Mark the number of pieces in series and in parallel.

Readings.—Take magnetization curves of the apparatus, varying the length and the cross-section of the circuit by adding pieces in series and in parallel. Before beginning the first run make a few preliminary trials so as to select proper values of the steps in changing the current and of the resistance in the galvanometer circuit. If desired, the method of reversals may be used instead of increasing the current step by step. Beginning with the zero current, increase the current to say 2 amp. by closing the switch, and read the galvanometer deflection. Open the galvanometer circuit and slowly increase the current say to 3 amp. Close the galvanometer circuit and quickly reverse the double throw switch. The flux is changed from

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$+\Phi$ to $-\Phi$, so that the change in flux is 2Φ. This value must be used in formula (2) of Exp. E 201–1. Now raise the current to say 4 amp., and again reverse rapidly. With this method twice the total flux is measured in each case, and not the additional flux as in the step-by-step method. When the galvanometer deflections increase beyond the limit of the scale, more resistance is to be connected into its circuit, so as to reduce its sensitiveness.

(*a*) After the preliminary trials, place two U-shaped pieces in the exciting coils, press them tight together end to end, and demagnetize the circuit thoroughly. Take a magnetization curve and again demagnetize the circuit.

(*b*) Repeat the test with two sets of U-shaped pieces connected magnetically in parallel and excited by the same coils; also with three pairs of pieces if such are available.

(*c*) Take again two U-shaped pieces and interpose two straight rods between them so as to form a longer circuit. Clamp the whole tightly together and demagnetize the circuit thoroughly. Take a magnetization curve and then demagnetize the circuit.

(*d*) Repeat the preceding test, using four U-shaped pieces and four straight pieces.

Before leaving the room, measure the dimensions of the cores, ask about the number of turns in the coils, find out the galvanometer constant, and the correction of the ammeter if any.

Report.—(1) Plot curves of flux against exciting ampere-turns, one curve for each combination of the cores.

(2) Show from these curves that, at a certain flux density, the number of ampere-turns required is proportional to the length of the circuit and does not depend upon its cross-section.

(3) Show that the number of ampere-turns necessary to produce a given flux increases faster than the decrease in the cross-section of the magnetic circuit; explain how this fact is due to saturation in the iron.

(4) The ratio of the magnetomotive force to the flux is called the *reluctance* of the magnetic circuit. It is analogous to the resistance of an electric circuit, the resistance being the ratio of the electromotive force to the current. Show from the results of your experiment that, neglecting saturation, the reluctance is directly proportional to the length of the magnetic circuit and is inversely proportional to its cross-section. A similar relation holds for the resistance of an electrical conductor.

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EXPERIMENT E 202-1. PRELIMINARY STUDY OF A DIRECT-CURRENT MACHINE

Apparatus.—Shunt-wound machine to be studied and a suitable drive; field ammeter; main ammeter; voltmeter; field rheostat; load rheostat; starting rheostat; double-pole switch and fuses for the main circuit (or a circuit breaker); single-pole switch for the field circuit; speed counter (or tachometer).

The purpose of the experiment is to familiarize the student with the structural details and the principal operating features of a direct-current machine. The experiment consists of three parts: making drawings and specifications of the machine; running it as a generator; and running it as a motor. The experiment may profitably be extended over two laboratory periods, or the part referring to the operation as a motor may be omitted until the student is ready to take up the brake tests on direct-current motors (Experiments E 205-1 and E 205-2).

Drawings and Specifications of the Machine.—Assume the machine to be bisected by a vertical plane through the geometrical axis of the shaft. Make a sketch of what would be visible in such a longitudinal section of the machine, naming the parts and marking the dimensions.

Then assume the machine to be bisected by a vertical plane perpendicular to the shaft, and passing through the armature. Make a sketch as before of the principal parts as they would appear in such a transverse section.

In addition to the sketches called for in the above sections, make sketches of the commutator, the brushes and brush holders, the armature coil, and such other parts as do not show well in the principal drawings.

Ascertain the following data, in addition to those copied from the name plate:

Field.—Number of poles; material of the frame; material of the pole pieces, whether solid or laminated, bolted on or cast with the frame. Measure the resistance of the field winding.

Armature.—"Lap" wound or "wave" wound; wire or strap used for the armature conductors; armature core smooth or slotted, solid or laminated; armature coils held in place by means of wedges or by binding wires; number of ventilating ducts provided; armature stampings assembled on the shaft or on a "spider" keyed to the shaft. Measure the armature resistance from brush to brush.

Commutator.—Number of segments and their material; how they are insulated from one another; how the segments are held in place.

Brushes and brush holders.—Number of studs; number of brushes per stud; material of the brushes; provision for adjusting the brush pressure; provision for adjusting the position of the brushes on the commutator.

Bearings.—Provisions for lubrication.

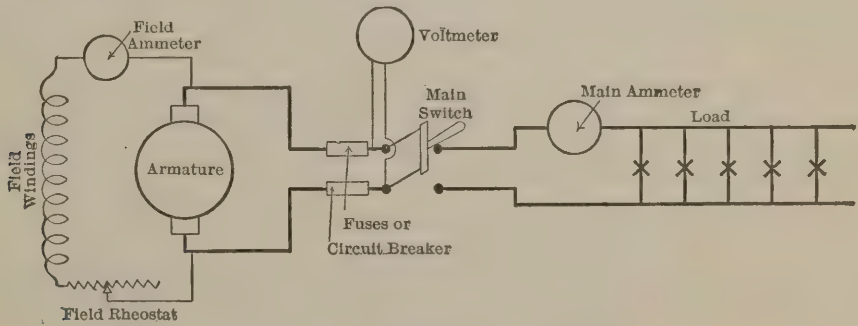

Fig. 1.—Connections as a Generator.

Operation as a Generator.—(1) See that the brushes are in good condition and properly placed, and that the machine is well oiled. Connect up for running as in Fig. 1, putting a suitable

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ammeter and regulating resistance in the field circuit, a second ammeter in the external circuit, and a voltmeter across the terminals. Place switches in both the external and the field circuits. **Have your connections approved by an instructor before starting the machine.**

(2) Open the switches in both the external and the field circuits, then drive the generator at its rated speed. Observe the voltmeter reading. This is the e.m.f. induced by the rotation of the armature coils in the weak magnetic field due to the residual magnetism of the field cores. Try the effect of change of speed upon the e.m.f. Send a small current from an external source through the field windings and note the effect upon the induced e.m.f.

(3) Insert the maximum resistance of the field rheostat, and leave the switch to the external circuit open. Close the field switch. The induced e.m.f. due to the residual magnetism will cause a small current through the field coils, which, if in the proper direction, will magnetize the field coils in the same direction as the residual magnetism. This stronger field in turn induces a stronger e.m.f., and therefore a greater field current, etc., and the machine will " build up." Note the increase in voltage at the brushes, as indicated by the voltmeter, and the rise in field current, as indicated by the field ammeter, during this process. If the field coils are not properly connected to the armature terminals, the flux due to the field current will weaken the residual magnetism and the machine cannot build up. In this case, the connections to the brushes must be reversed. Decrease the field resistance until the voltmeter indicates the normal voltage, at normal speed. Why does decreasing the field resistance increase the pressure at the brushes?

(4) Close the main switch and reduce the resistance of the load gradually until the full load is reached. What effect has increasing the current supplied by the machine upon the voltage at the brushes? Why? Bring the voltage to the normal value by adjusting the field rheostat, and run the machine at its normal voltage and speed. Determine the load current and compute the output of the generator in watts.

Operation as a Motor.—(1) Connect up as in Fig. 2; do *not* use any switch in the field circuit, because if this switch should be opened by an oversight, the motor may acquire a dangerous speed (run away).

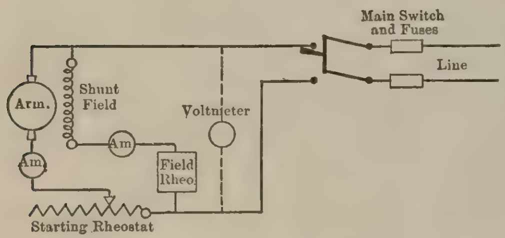

Fig. 2.—Connections for Operation as a Motor.

(2) Have all of the starting resistance " in " and all of the field resistance " out." Close the main switch and, as the motor starts, cut the starting resistance out in steps until the armature is connected directly across the line.

(3) To stop the motor, open the main circuit and then connect all of the starting resistance in the circuit so as to prepare the motor for the next run. *Always see to it that the armature is protected by the starting resistance when the motor stands still.*

(4) Reverse the armature terminals and start the motor in order to see that its direction of rotation is reversed. Try the same with the field terminals. Finally, reverse the line terminals to find that the motor continues to run in the same direction. Explain the reasons for each of the preceding.

(5) Having brought the motor up to its speed, slowly reduce the field current by means of the field rheostat, and note that the speed increases. Take a few readings so as to plot a curve of field current vs. speed. Ask the instructor about the safe maximum speed of the machine. If the brush rigging permits, try to regulate the speed by shifting the brushes.

Report.—(1) Make neat drawings of the machine, approximately to scale.

(2) Describe the construction of the machine.

(3) Give data and answer the questions asked under " Operation as a Generator."

(4) Report your findings from the tests called for under " Operation as a Motor."

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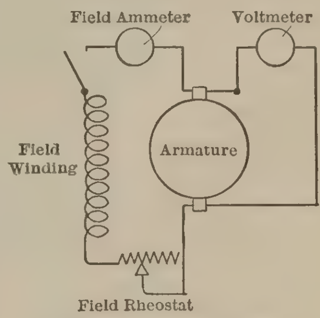
ELECTRICAL TESTING

EXPERIMENT E 203–1. NO-LOAD CHARACTERISTICS OF A SHUNT-WOUND GENERATOR

Apparatus.—Shunt-wound machine with a suitable drive; field ammeter; voltmeter; field rheostat; switch for the field circuit; speed-counter (or tachometer).

The purpose of the experiment is to investigate the relation between the exciting current and the terminal voltage of a shunt-wound machine at no-load. Since the induced voltage at a constant speed is proportional to the useful flux of the machine, the experiment is also a study of the magnetic circuit of the machine. It is advisable to have the experiment preceded by E 202–1 " Preliminary Study of a Direct-current Machine."

Connections.—Connect the apparatus as in the figure. If the polarity of the brushes is known, connect the instruments so as to read in the right direction; if not, start the machine and bring it up to a speed sufficient to read the voltage between the brushes, so as to determine their polarity with a voltmeter. **Have your connections approved by an instructor before starting the machine.**



Connections for the Test.

Data Sheet.—Record terminal volts, field amperes and the speed of the machine.

Readings.—(1) Bring the machine up to its rated speed and excite the field. Begin readings with the highest possible value of the field current, in other words, with the field rheostat short-circuited. Read field amperes, volts and the speed of the machine. Reduce the field current in steps, and at each step take similar readings. The value of the residual magnetism at the beginning of the experiment is rather indefinite; therefore, it is advisable to begin the excitation at its maximum and reduce to zero. After this, take readings with an increasing field current, in order to see the influence of residual magnetism. This is somewhat analogous to taking a hysteresis loop (Experiment E 201–1).

(2) The induced voltage is proportional to the speed of the machine when the field current is kept constant; this is according to the fundamental law of induction. To prove this experimentally, select a field excitation and run the machine within as wide a range of speed as the driving motor will permit. Keep the exciting current constant by regulating the field rheostat, or excite the machine from a separate source. Repeat this run with two or three different values of field current.

(3) Investigate the ability of the machine to excite itself. Run it at the rated speed, and find the rheostat notch on which the field just begins to build up. Measure the corresponding field current, the final voltage, and the number of seconds of time from the closing of the field switch to the moment when the voltage reaches its final value. Repeat the same experiment with less resistance in the field rheostat, and at different speeds of rotation.

Report.—(1) Plot the no-load saturation curve, that is, terminal volts against field current as abscissæ, at the rated speed. Where the speed was not exactly right, correct the voltages in direct proportion.

(2) Plot curves which show that the induced voltage is directly proportional to the speed.

(3) Give the numerical results on self-excitation.

(4) Answer the following questions:

(*a*) Would the machine excite itself if driven in the opposite direction?

(*b*) If the residual magnetism is too weak to build up the field at the normal speed, would it help the matter to speed up the machine and then return to the rated speed?

(*c*) Why is the lower portion of the no-load characteristic practically a straight line?

(*d*) Would the no-load characteristic be affected if the brushes be shifted from the neutral position?

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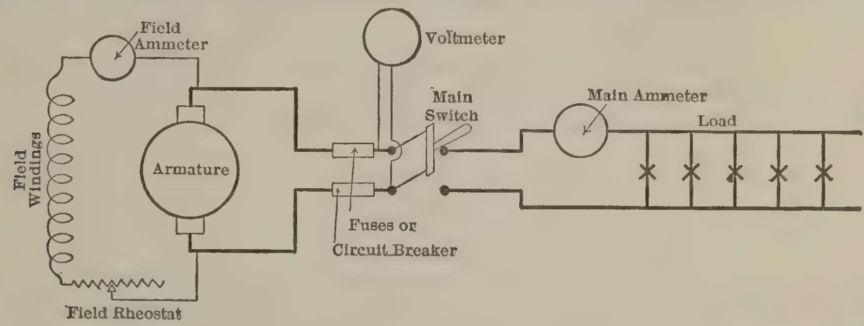
ELECTRICAL TESTING

EXPERIMENT E 203-2. VOLTAGE CHARACTERISTICS OF A SHUNT-WOUND GENERATOR.

Apparatus.—Shunt-wound generator with a suitable drive; main ammeter; field ammeter; voltmeter; load rheostat; field rheostat; double-pole switch and fuses for the main circuit (or a circuit-breaker); single-pole switch for the field circuit; speed-counter (or a tachometer).

The purpose of the experiment is to investigate fluctuations in the terminal voltage of the machine caused by fluctuations in the load. It is assumed that the machine is left without attention, so that no adjustments of the field current are made in order to keep the voltage constant when the load varies. In some cases a generator operates under nearly such conditions in practice. The conditions are opposite to those in experiment E 203-3, "Excitation Characteristics of a Shunt-wound Generator," where it is assumed that the field current of the machine is being regulated all the time so as to keep the voltage constant. This experiment must be preceded by experiments E 202-1, "Preliminary Study of a Direct-current Machine," and E 203-1, "No-load Characteristics of a Shunt-wound Generator," or at least by one of them.



Connections.—Connect the apparatus as in the diagram. If the polarity of the brushes is known, connect the instruments so as to read in the right direction; if not, start the machine at no-load and bring it up to a speed sufficient to read the voltage between the brushes, so as to determine their polarity with a voltmeter. Leave both switches open, and set both rheostats at a maximum of resistance. **Have your connections approved by an instructor before starting the machine.**

Data Sheet.—Record your readings on a data sheet similar to the one shown below. Before beginning the readings, copy the name-plate of the machine and note the make and the serial numbers of the measuring instruments, also their correction constants if any. The speed must be kept constant during the whole test, but small, unavoidable deviations must be recorded on the data sheet.

Data Sheet

Normal voltage at.............................load.

	Field Amps.	Load Amps.	Volts.	Speed.
Instrument No.........				
Constant..............				

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Readings.—Bring the machine up to its rated speed, close the field switch, and excite the field to some value below normal. Close the main switch and carefully adjust the rheostats in such a way as to finally obtain the rated load current at the rated terminal voltage and at the rated speed. Record these readings, also the field current, and leave the field rheostat in this position for the rest of the run. By regulating the load rheostat, increase the current to about 25 per cent above the rated current and adjust the speed of the machine to its correct value. Take readings of volts, load amperes, and field current. Now decide as to the number of points desired on the curves and the approximate values of the load current for which readings are to be taken. For instance, if the rated current of the machine is 100 amps., the readings would begin at 125 amps., and a good curve would be obtained by reducing the load to 110, 100, 80, 60, 40, 20 amps., and finally to zero by opening the main switch. If time permits, readings should be taken at closer intervals, because there is always a possibility of one or two readings being off on account of some unnoticed error or inaccuracy.

If circumstances permit, take another set of readings corresponding to some different initial conditions; for example, a different voltage at full load, a slightly different speed, a different position of the brushes, etc. Such tests help to form a more complete picture of the performance and the properties of the machine. If requirement (3) of the report is specified, measure the resistance of the armature, including that of the brushes.

Report.—(1) Plot to armature amperes as abscissae the following quantities: terminal volts, field amperes, load amperes, and the output in kilowatts. The armature current is the sum of the current in the load circuit and that in the field windings. The output is equal to terminal volts times terminal amperes divided by 1000.

(2) Figure out the per cent voltage regulation of the machine or

$$100\times\frac{E_1-E_0}{E_1},$$

where E_1 is the terminal voltage at the rated load and E_0 the no-load voltage. It is understood in the definition that the speed and the setting of the field rheostat (not the field current) are the same at no-load as at full-load.

(3) Supplement the curves by a curve of the induced e.m.f. The induced e.m.f. is equal to the terminal voltage increased by the amount, $i_a r_a$, of voltage drop in the armature, where i_a is the armature current, and r_a the resistance of the armature including that of the brushes.

(4) Plot on the same curve sheet a curve of the voltage induced at no-load, at the corresponding values of field current. The difference between the curves (4) and (3) is a measure of the armature reaction.

(5) Answer the following questions:

(*a*) What are the three causes of voltage drop in a loaded generator, as compared to the no-load voltage?

(*b*) Why should the resistance of the shunt winding be high as compared to that of the armature?

(*c*) What is meant by "armature reaction"?

(*d*) What means are employed in practice to keep the terminal voltage approximately constant with varying load?

(*e*) Why is the load switch kept open until the field has been built up?

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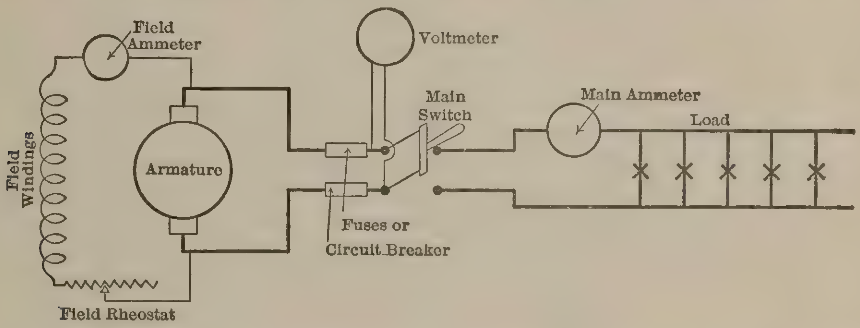
ELECTRICAL TESTING

EXPERIMENT E 203–3. EXCITATION CHARACTERISTICS OF A SHUNT-WOUND GENERATOR

Apparatus.—Shunt-wound generator with a suitable drive; main ammeter; field ammeter; voltmeter; load rheostat; field rheostat; double-pole switch and fuses for the main circuit (or a circuit-breaker); single-pole switch for the field circuit; speed-counter (or tachometer).

The purpose of the experiment is to investigate the necessary variations in the field current in order to keep the terminal voltage of the machine constant when the load varies. In some cases a generator operates under nearly such conditions of constant attention in practice. The conditions are opposite to those in experiment E 203–2 "Voltage Characteristics of a Shunt-wound Generator," where it is assumed that the machine is left without attention. This experiment must be preceded by Experiments E 202–1 "Preliminary Study of a Direct-current Machine" and E 203–1 "No-load Characteristics of a Shunt-wound Generator," or at least by one of them.

Connections.—Connect the apparatus as in the diagram. If the polarity of the brushes is known, connect the instruments so as to read in the right direction; if not, start the machine at no



load and bring it up to a speed sufficient to read the voltage between the brushes, so as to determine their polarity with a voltmeter. Leave both switches open, and set both rheostats at a maximum of resistance. **Have your connections approved by an instructor before starting the machine.**

Data Sheet.—Record your readings on a data sheet similar to the one shown below. Before beginning the readings, copy the name plate of the machine and note the make and the serial numbers of the measuring instruments, also their correction constants if any. The speed and the voltage must be kept constant during each run, but small, unavoidable deviations must be recorded on the data sheet.

	Load Amps.	Field Amps.	Volts.	Speed.
Inst. No.				
Const.				

Readings.—Bring the machine up to its rated speed, close the field switch, and excite the field to some value below normal. Close the main switch and adjust the rheostats in such a way

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as to obtain finally the rated terminal voltage and a load current of about 25 per cent in excess of the rated current of the machine. Record these readings. Now decide as to the number of points desired on the curves and the approximate values of the load current for which readings are to be taken. For instance, if the rated current of the machine is 100 amps., the readings would begin at about 125 amps., and a good curve would be obtained by reducing the load to 110, 100, 80, 60, 40, 20 amp., and finally to zero by opening the main switch. If time permits, readings should be taken at closer intervals, because there is always a possibility of one or two readings being practically valueless on account of some unnoticed error or inaccuracy.

If circumstances permit, take another set of readings corresponding to a different terminal voltage. At a higher voltage, the machine is more highly saturated and the per cent variation in field current is less, although the field current itself is greater. At a low voltage the field current is small but its per cent variation is much greater. Such tests help to make a more complete picture of the performance and the properties of the machine. If requirement (3) of the report is specified, measure the resistance of the armature including that of the brushes.

Report.—(1) Plot to armature amperes as abscissæ, the following quantities: terminal volts, field amperes, load amperes and the output in kilowatts. The armature current is the sum of the current in the load circuit and that in the field winding. The output is equal to terminal volts times terminal amperes divided by 1000.

(2) Figure out the per cent field current regulation of the machine, defined as,

$$100\times\frac{i_1-i_0}{i_1},$$

where i_1 is the field current at full load and i_o that at no load. It is understood in this definition that the speed and the voltage are the same at no load as at full load.

(3) Supplement the curves by a curve of the induced e.m.f. The induced e.m.f. is equal to the terminal voltage increased by the amount of voltage drop, i_ar_a, in the armature, where i_a is the armature current, and r_a the resistance of the armature including that of the brushes.

(4) Plot on the same curve sheet a curve of the voltage induced at no load, at the corresponding values of the field current. The difference between curves (4) and (3) is a measure of the armature reaction.

(5) Answer the following questions:

(*a*) What are the two causes for which it is necessary to increase the field current with the load, in order to keep the terminal voltage constant?

(*b*) Why should the resistance of the shunt-winding be high as compared to that of the armature?

(*c*) What is meant by "armature reaction?"

(*d*) What means are employed in practice to keep the terminal voltage approximately constant with varying load?

(*e*) Why is the load switch kept open until the field has been built up?

(*f*) Why is per cent field current regulation smaller in a highly saturated machine?

EXPERIMENT E 204–1. LOAD CHARACTERISTICS OF A SERIES-WOUND GENERATOR

Apparatus.—Series-wound generator with a suitable drive; ammeter; voltmeter; load rheostat; double-pole switch and fuses for the main circuit (or circuit breaker); speed-counter (or tachometer).

The purpose of the experiment is to investigate the relation between the load current and the terminal voltage of a series-wound generator. While such a generator is seldom used in practice, its characteristics are of interest because many shunt-wound generators are provided with an additional series winding and are then called compound-wound generators.

Connections.—Connect the load-rheostat across the terminals of the machine in series with the main switch and the ammeter. Connect the voltmeter across the terminals of the machine. **Have your connections approved by an instructor before starting the machine.**

Data Sheet.—Record volts, amperes and speed. The speed must be kept constant, but small unavoidable deviations must be recorded on the data sheet. If a run is to be made with the field weakened (see below) provide a separate column for the field current.

Readings.—Bring the machine up to its rated speed with the main switch open. Cut in as much of the load resistance as possible and close the main switch. Carefully cut the resistance out and build up the voltage of the machine. Go up to the safe limit of the current and take the first set of readings at this limit. Decide upon the number of steps, gradually cut the resistance out, and take the readings at each step. At least ten steps are necessary in order to obtain a satisfactory curve. Having reduced the current to zero, increase the load again and take another load curve with the current increasing, so as to find out the effect of the residual magnetism.

The load characteristics of a series-wound generator may be varied by shunting part of the armature current around the field. Connect a high-resistance rheostat across the field winding of the machine and insert a second ammeter in series with the field. Adjust the field rheostat so as to have the field current equal to say 80 or 90 per cent of the armature current, and take a load curve similar to the one taken before.

Report:—(1) Plot to armature amperes as abscissæ, the terminal volts and the output in kilowatts.

(2) If a run has been made with the field weakened, plot the results on the same curve sheet, viz., the field current, terminal volts and the output in kilowatts.

(3) Answer the following questions:

(*a*) Why is a series-wound generator not suitable for ordinary light and power circuits?

(*b*) Why should the resistance of the series winding be low while that of shunt winding is high?

(*c*) What would you do if the machine failed to excite itself, due to lack of residual magnetism or to a residual magnetism of the wrong polarity?

(*d*) Explain the shape of the voltage curve with a weakened field as compared to that with a full field.

ELECTRICAL TESTING

EXPERIMENT E 205–1. BRAKE TEST ON A SHUNT MOTOR

Apparatus.—Shunt-wound motor; starting rheostat; field rheostat; Prony brake; main ammeter; field ammeter; voltmeter; switch and fuses for the main circuit (or circuit breaker); speed counter (or tachometer).

The purpose of the experiment is to investigate the electrical characteristics of a shunt-wound motor similar to those shown in Fig. 1. Such characteristics are important for the prospective user of a motor, in order to determine if a motor offered for sale is suitable for his purpose. This experiment should be preceded by Experiments E 202–1 "Preliminary Study of a Direct Current Machine" and E 203–1 "No load Characteristics of a Shunt-wound Generator" or at least by one of them.

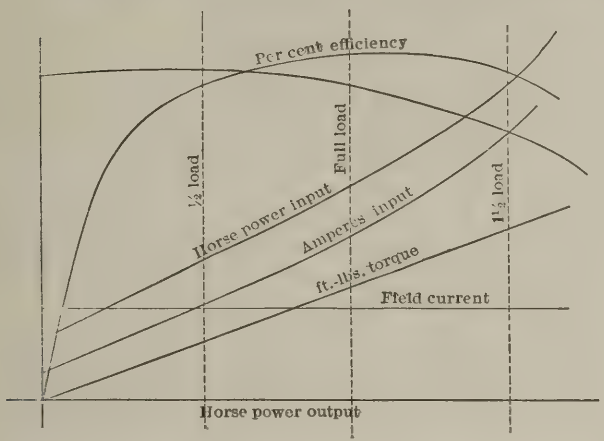

Fig. 1.—Electrical Characteristics of a Shunt-wound Motor.

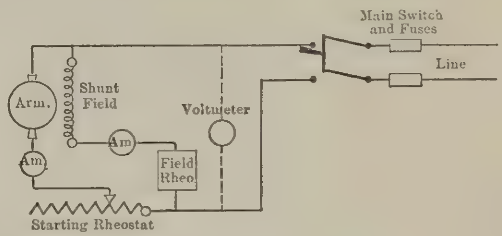

Fig. 2.—Connections for the Test.

Connections.—Connect the apparatus as shown in Fig. 2; have all of the field resistance cut out and the whole starting resistance connected in. **Have your connections approved by an instructor before starting the machine.** Start the machine slowly in order to see if it runs in the proper direction for the Prony brake. If not, reverse either the field or the armature terminals; look out for the beam of the brake that it does not strike you.

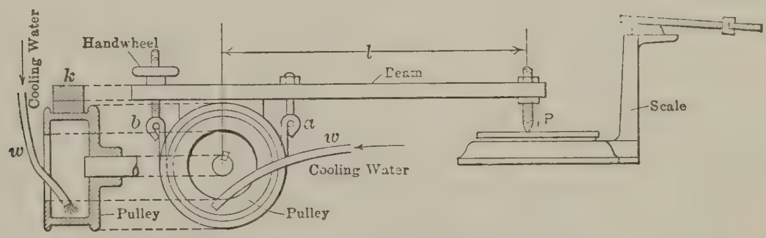

Fig. 3.—Prony Brake.

Data Sheet.—Record your readings on a data sheet similar to the one shown below. Before beginning the readings, copy the name plate of the machine and note the make and the serial numbers of the measuring instruments, also their correction constants, if any. The field current must be kept constant during each run, but small unavoidable deviations must be recorded on the data sheet.

 (over)

	Arm. Amps.	Field Amps.	Volts.	Revs. per Min.	Torque lbs. (or kgr.)
Inst. No.					
Const.					

Prony Brake.—The simplest device for loading motors is a Prony brake, a form of which is shown in Fig. 3, in side view and in cross-section. It consists of an iron band, *ab*, lined with soft wood or with heavy canvas. The band embraces the pulley of the motor, and is fastened to a beam, the other end of which rests on a scale.

When the motor revolves, friction is developed between the lining of the brake and the pulley; the power of the motor is thus converted into heat. The brake pressure is regulated by a hand-wheel, and in this way any desired load is obtained. The turning moment, or the *torque*, as it is called, is measured on the scale.

In most cases it is necessary to carry away the heat developed by friction, in order to prevent burning of the brake lining. The pulley, shown in the sketch, is cooled by a stream of water from the pipe w (see cross-section to the left); the water is thrown by centrifugal force against the inner surface of the face of the pulley and the flange prevents it from being spilled.

If P is the net pressure in pounds on the scale at the end of a lever l feet long, the pressure at the end of a lever one foot long is Pl lbs.; consequently the work in foot-pounds, performed during one minute, is $Pl \times 2\pi n$, where n is the number of revolutions of the motor per minute. The same in horse-power is

$$\frac{Pl \times 2\pi n}{33000},$$

or

$$\text{horse-power} = \frac{Pln}{5252}.$$

The net pressure is obtained by subtracting from the actual scale reading the pressure exerted upon the scale when the motor is stationary with the power off. This initial pressure simply represents the unbalanced weight of the brake. Move the arm up and down to eliminate the friction in the bearings of the motor when obtaining this initial pressure.

In the metric system, if P is in kilograms and l in meters, the formula is

$$\text{kilowatts output} = \frac{Pl \times 2\pi n/60 \times 9.81}{1000} = \frac{Pln}{973}$$

Readings.—Before starting the motor, determine the initial pressure of the brake arm upon the scale, as explained above. Begin the test with the highest load, say 25 per cent overload; read armature amperes, field amperes, terminal voltage, speed, and brake load. Then gradually reduce the load to zero, taking a sufficient number of readings (from 8 to 10) for plotting curves. The field current and the terminal voltage must be kept constant throughout the whole test.

Take a few points with the field current 10 and 20 per cent below normal. Also make runs at a line voltage, say 10 per cent above and a like amount below normal, in order to see the influence of this factor upon the performance of the motor.

Report.—(1) Plot performance curves similar to those shown in Fig. 1.

(2) If readings have been taken with the field current below normal, and at a different line voltage, indicate the results on the same curve sheet, preferably in a different colored ink.

(3) Answer the following questions:

(*a*) What makes a shunt motor slow down when the load increases?
(*b*) Why does a shunt motor run faster with a weakened field?
(*c*) Why is the efficiency low at a small load?
(*d*) Why does the efficiency decrease beyond a certain load?

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ELECTRICAL TESTING

EXPERIMENT E 205–2. BRAKE TEST ON A SERIES MOTOR

Apparatus.—Series-wound motor; Prony brake; ammeter; voltmeter; starting rheostat; double-pole switch and fuses for the main circuit (or a circuit breaker); speed counter (or tachometer); underload circuit breaker (desirable, but not strictly necessary).

The purpose of the experiment is to investigate the electrical characteristics of a series-wound motor similar to those shown in Fig. 1. Such characteristics are important for a prospective user of a motor, in order to determine if the motor offered for sale is suitable for his purpose. This experiment ought to be preceded by experiments E 202–1 "Preliminary study of a direct current machine" and E 203–1 "No-load characteristics of a shunt-wound generator" or at least by one of them.

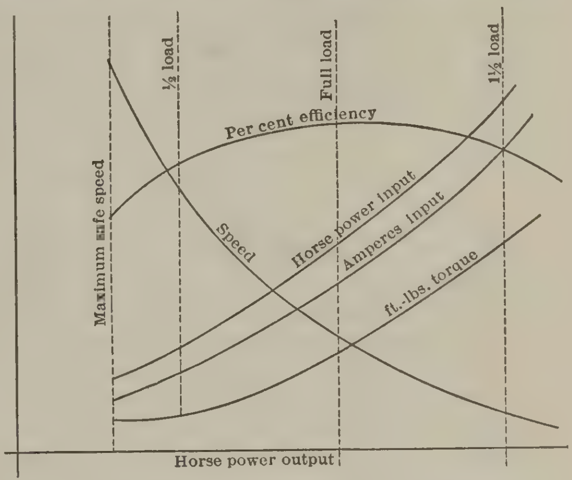


Fig. 1.—Electrical Characteristics of a Series Motor.

Connections.—Connect the apparatus as shown in Fig. 2 and have all the starting resistance in the circuit. **Have your connections approved by an instructor before starting the machine.**

Prony Brake.—The simplest device for loading motors is a Prony brake, a form of which is shown in Fig. 3, in side view and in cross-section. It consists of an iron band, *ab*, lined with soft wood or with heavy canvas. The band embraces the pulley of the motor, and is fastened to a beam, the other end of which rests on a scale.

When the motor revolves, friction is developed between the lining of the brake and the pulley;

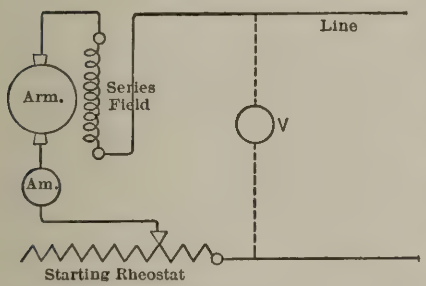


Fig. 2.—Connections for the Test.

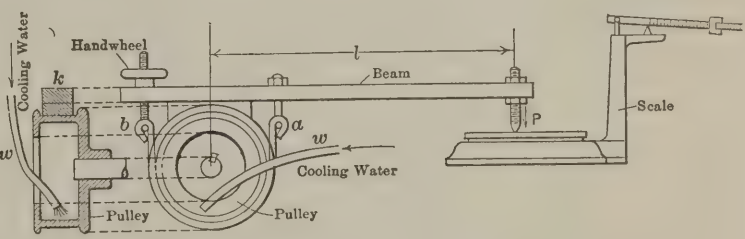


Fig 3.—Prony Brake.

the power of the motor is thus converted into heat. The brake pressure is regulated by a hand-wheel, and in this way any desired load is obtained. The turning moment, or the *torque*, as it is called, is measured on the scale.

In most cases it is necessary to carry away the heat developed by friction, in order to prevent burning of the brake lining. The pulley, shown in the sketch, is cooled by a stream of water from the pipe w (see cross-section to the left); the water is thrown by centrifugal force against the inner surface of the face of the pulley and the flange prevents it from being spilled.

If P is the net pressure in pounds on the scale at the end of a lever l feet long, the pressure

at the end of a lever one foot long is Pl lbs.; consequently the work in foot-pounds, performed during one minute, is $Pl \times 2\pi n$, where n is the number of revolutions of the motor per minute. The same in horse-power is

$$\frac{Pl \times 2\pi n}{33000},$$

or

$$\text{horse-power} = \frac{Pln}{5252}.$$

The net pressure is obtained by subtracting from the actual scale reading the pressure exerted upon the scale when the motor is stationary with the power off. This initial pressure simply represents the unbalanced weight of the brake. Move the arm up and down to eliminate the friction in the bearings of the motor when obtaining this initial pressure.

In the metric system, if P is in kilograms and l in meters, the formula is

$$\text{kilowatts output} = \frac{Pl \times 2\pi n / 60 \times 9.81}{1000} = \frac{Pln}{973}$$

Starting the Machine.—Start the machine slowly in order to see if it runs in the proper direction for the Prony brake. If not, reverse either the field or the armature terminals; look out for the beam of the brake that it does not strike you.

An Important Precaution.—The student must be very careful not to let the motor run away. With a shunt motor the brake can safely be released, since the speed of the motor is practically the same at no load as when loaded. In a series motor the speed increases enormously as soon as the load is taken off, and either the armature, the commutator, or the bearings are sure to be damaged, if the motor be allowed to run at this speed. For this reason, *always open the circuit before releasing the brake;* or at least have a sufficient resistance inserted into the circuit, to keep down the speed.

As an additional precaution against the motor running away, an *underload circuit breaker* may be connected into the circuit; when the load is taken off, the current falls below a certain limit, and this device automatically opens the circuit. The student should not, however, rely absolutely on this circuit breaker. It may "stick" just when it is necessary for it to act. It is best to have one man of the section stand near the main switch, and open the circuit if the motor should reach a dangerous speed.

Data Sheet.—Record your readings in a data sheet similar to the one shown below. The column for field amperes is necessary only if a run is made with the field current weakened.

	Arm. Amps.	Field Amps.	Volts.	Revs. per min.	Torque Lbs. (or kgr.)
Inst. No.					
Const.					

Readings.—Before starting the motor, determine the initial pressure of the brake arm upon the scale, as explained above. Begin the test at the highest value of the current which the motor can safely carry. Read amperes, volts, speed and the brake pressure. Reduce the load in approximately equal steps until the safe limit of the motor speed is reached. At least ten steps ought to be taken in order to obtain satisfactory performance curves.

The performance characteristics of a series-wound motor may be varied within certain limits by shunting part of the current around the field winding. If circumstances permit, put a high-

resistance rheostat around the field winding of the motor and connect a second ammeter to read the field current. Adjust the rheostat so that from 80 to 90 per cent of the total current flows through the field winding. Take a few readings for the performance curves of the motor so adjusted.

Report.—(1) Plot performance curves similar to those shown in Fig. 1.

(2) If readings have been taken with the field current below normal, indicate the results on the same curve sheet, preferably in a different colored ink.

(3) Answer the following questions:

(*a*) What makes a series motor run away when the load is removed?

(*b*) Why is the series motor used for electric traction and the shunt motor for shop drive?

(*c*) Explain the shape of the curves with the field weakened as compared to those with the full field.

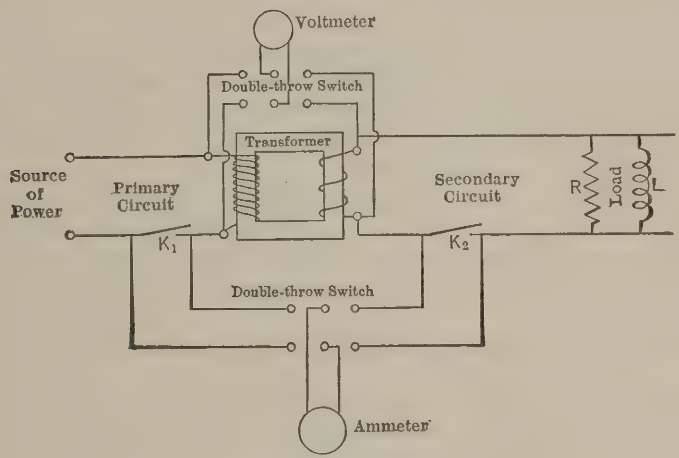
(*d*) Can the direction of rotation of a series motor be reversed by reversing the line terminals?

EXPERIMENT E 206-2. LOAD TESTS ON A TRANSFORMER

Apparatus.—Transformer; two ammeters; two voltmeters; wattmeter; load rheostat; reactance coil (load); switch and fuses.

Note.—Instead of two voltmeters, a voltmeter connected to a double-throw switch may be used. An ammeter may also be transferred between the primary and the secondary circuits by using short-circuiting switches (see diagram).

The purpose of the experiment is to determine the values of the secondary terminal voltage when the primary voltage is kept constant and the load is varied. At no load the ratio of the voltages, primary and secondary, is very nearly equal to that of the respective number of turns; but when currents flow through the transformer windings, these currents cause an ohmic drop



Connections for the Test.

and an inductive drop within the transformer. The result is that the secondary terminal voltage is lower than that at no load. This circumstance is of importance when incandescent lamps are connected to the transformer, because the voltage across the lamps depends on the number of lamps burning. In the specifications on the delivery of a transformer, the fluctuations between the no-load voltage and the full-load voltage are usually limited to a certain percentage, depending upon the service for which the transformer is intended. The purpose of this experiment is to show the student the order of magnitude of voltage drop and also its dependence upon the load amperes and the power factor. With lagging currents, the lower the power factor the lower is the secondary terminal voltage.

Connections.—The connections are as shown in the diagram, provided that only one voltmeter and one ammeter are used. The switches K_1 and K_2 must be closed while transferring the ammeter, and one of them must be opened when taking a reading. If two ammeters are used they are connected in place of the switches K_1 and K_2. The reactance, L, is shown in parallel with the resistance, R, but the two may also be connected in series.

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Data Sheet.—The data sheet may be similar to the one shown below.

	NON-INDUCTIVE LOAD.					INDUCTIVE LOAD....AMPS. CONST.					
	Prim. Amps.	Prim. Volts.	Sec. Amps.	Sec. Volts.	Sec. Watts.	Prim. Amps.	Prim. Volts.	Sec. Amps.	Sec. Volts.	Sec. Watts.	Power Factor.
Inst. No.											
Const.											

Readings.—1. Apply a certain load, say 25 per cent overload, entirely non-inductive, and gradually decrease it, at the same time introducing more and more of an inductive load,—say a choke coil in parallel with the rheostat. Regulate the load so as to keep *total amperes constant*, and observe the variation of the secondary voltage as the power factor decreases. The same test can be repeated for 100 per cent load, 75 per cent load, etc.

2. Now again take a certain non-inductive load and gradually add to it some inductive load, keeping the *total watts constant.* Observe the regulation under these conditions. In this case it may be better to begin with the lowest power factor available (largest current), as otherwise the ammeter and wattmeter may be overloaded and damaged. Several curves should be taken, for various values of watts.

3. Determine the ratio of voltages at no load, if this has not been done in a preceding experiment.

The student must keep in mind that voltages must be read to the best possible accuracy, because the difference between the no-load voltage and the full-load voltage is only a few per cent and this difference may be entirely lost or reversed with careless readings. It is only fair to state that in practice the voltage drop in a transformer is hardly ever determined by the direct method outlined in this experiment, but usually from a short-circuit test.*

Report.—1. Give the actual connections used during the experiment.

2. Plot to the power factor values as abscissæ, curves of the volts for constant amperes. Plot on the same sheet, curves of the corresponding watts.

3. Plot similar curves for the tests in which the watts were kept constant, showing also the corresponding amperes.

Note 1.—Per cent voltage drop in a transformer is usually small, therefore, in plotting curves, the student is advised to use a suppressed scale for voltages. For instance, in a 110-volt transformer it is sufficient to mark 100 at the origin and then mark the divisions 105 and 110.

Note 2.—The inductive drop in a transformer depends upon the arrangement of the primary and the secondary coils. The more the coils are interposed (or sandwiched in), the more the leakage flux is broken up and the inductive drop reduced. If a transformer is available in which the connections and the arrangement of the coils may be varied at will, it is advisable to take two sets of readings, one set with the coils interposed as much as possible and the other set with all the primary coils on one side of the core and all the secondary coils on the other side. It will be found that the voltage drop is several times higher in the second case.

* See V. Karapetoff, "Experimental Electrical Engineering," Vol. II, Arts. 498 to 504.

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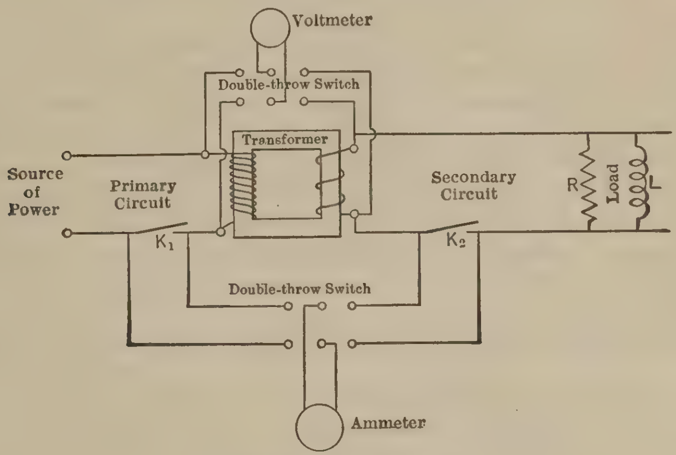
EXPERIMENT E 206–2. LOAD TESTS ON A TRANSFORMER

Apparatus.—Transformer; two ammeters; two voltmeters; wattmeter; load rheostat; reactance coil (load); switch and fuses.

Note.—Instead of two voltmeters, a voltmeter connected to a double-throw switch may be used. An ammeter may also be transferred between the primary and the secondary circuits by using short-circuiting switches (see diagram).

The purpose of the experiment is to determine the values of the secondary terminal voltage when the primary voltage is kept constant and the load is varied. At no load the ratio of the voltages, primary and secondary, is very nearly equal to that of the respective number of turns; but when currents flow through the transformer windings, these currents cause an ohmic drop



Connections for the Test.

and an inductive drop within the transformer. The result is that the secondary terminal voltage is lower than that at no load. This circumstance is of importance when incandescent lamps are connected to the transformer, because the voltage across the lamps depends on the number of lamps burning. In the specifications on the delivery of a transformer, the fluctuations between the no-load voltage and the full-load voltage are usually limited to a certain percentage, depending upon the service for which the transformer is intended. The purpose of this experiment is to show the student the order of magnitude of voltage drop and also its dependence upon the load amperes and the power factor. With lagging currents, the lower the power factor the lower is the secondary terminal voltage.

Connections.—The connections are as shown in the diagram, provided that only one voltmeter and one ammeter are used. The switches K_1 and K_2 must be closed while transferring the ammeter, and one of them must be opened when taking a reading. If two ammeters are used they are connected in place of the switches K_1 and K_2. The reactance, L, is shown in parallel with the resistance. R, but the two may also be connected in series.

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Data Sheet.—The data sheet may be similar to the one shown below.

	NON-INDUCTIVE LOAD.					INDUCTIVE LOAD....AMPS. CONST.					
	Prim. Amps.	Prim. Volts.	Sec. Amps.	Sec. Volts.	Sec. Watts.	Prim. Amps.	Prim. Volts.	Sec. Amps.	Sec. Volts.	Sec. Watts.	Power Factor.
Inst. No.											
Const.											

Readings.—1. Apply a certain load, say 25 per cent overload, entirely non-inductive, and gradually decrease it, at the same time introducing more and more of an inductive load,—say a choke coil in parallel with the rheostat. Regulate the load so as to keep *total amperes constant*, and observe the variation of the secondary voltage as the power factor decreases. The same test can be repeated for 100 per cent load, 75 per cent load, etc.

2. Now again take a certain non-inductive load and gradually add to it some inductive load, keeping the *total watts constant*. Observe the regulation under these conditions. In this case it may be better to begin with the lowest power factor available (largest current), as otherwise the ammeter and wattmeter may be overloaded and damaged. Several curves should be taken, for various values of watts.

3. Determine the ratio of voltages at no load, if this has not been done in a preceding experiment.

The student must keep in mind that voltages must be read to the best possible accuracy, because the difference between the no-load voltage and the full-load voltage is only a few per cent and this difference may be entirely lost or reversed with careless readings. It is only fair to state that in practice the voltage drop in a transformer is hardly ever determined by the direct method outlined in this experiment, but usually from a short-circuit test.*

Report.—1. Give the actual connections used during the experiment.

2. Plot to the power factor values as abscissæ, curves of the volts for constant amperes. Plot on the same sheet, curves of the corresponding watts.

3. Plot similar curves for the tests in which the watts were kept constant, showing also the corresponding amperes.

Note 1.—Per cent voltage drop in a transformer is usually small, therefore, in plotting curves, the student is advised to use a suppressed scale for voltages. For instance, in a 110-volt transformer it is sufficient to mark 100 at the origin and then mark the divisions 105 and 110.

Note 2.—The inductive drop in a transformer depends upon the arrangement of the primary and the secondary coils. The more the coils are interposed (or sandwiched in), the more the leakage flux is broken up and the inductive drop reduced. If a transformer is available in which the connections and the arrangement of the coils may be varied at will, it is advisable to take two sets of readings, one set with the coils interposed as much as possible and the other set with all the primary coils on one side of the core and all the secondary coils on the other side. It will be found that the voltage drop is several times higher in the second case.

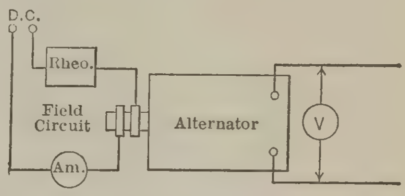
* See V. Karapetoff, "Experimental Electrical Engineering," Vol. II, Arts. 498 to 504.

EXPERIMENT E 207-1. NO-LOAD CHARACTERISTICS OF AN ALTERNATOR

Apparatus.—The alternator with a suitable drive; voltmeter; field rheostat; switch and fuses; speed counter (or tachometer).

The purpose of the experiment is to investigate the dependence of the voltage induced in the armature conductors upon the exciting current and the speed. When the field current is kept constant (constant flux) and the speed of rotation is varied, the induced voltage is directly proportional to the number of revolutions per minute, according to the fundamental law of induction. At a constant speed the induced voltage is at first proportional to the field current, but then increases more and more slowly, due to saturation in the iron parts of the magnetic circuit. A curve which gives the relation between the field current and the induced voltage at a constant speed is called the *no-load characteristic* of the alternator.

Connections.—The connections for a single-phase machine are shown in the diagram. If a three-phase machine, only, is available, it is sufficient to take readings on one phase, having satisfied oneself that the three induced voltages are substantially equal.



Connections for the Test.

Data Sheet.—The data sheet must have columns for the field amperes, the induced volts and the speed.

Order of the Experiment.—1. Make rough sketches of the machine, especially its longitudinal and transverse cross-sections. Make detailed sketches of parts which do not show well in these two cross-sections.

2. Run the machine at its rated speed and increase the field excitation in steps; read the corresponding alternating voltages and field amperes. Take, also, readings with decreasing field current so as to investigate the influence of residual magnetism.

3. Having opened the field circuit, raise the speed of the machine to its highest safe limit and then excite the machine to the highest feasible value of voltage, determined for instance by the highest reading possible on the voltmeter. Keep the field current constant and reduce the speed to zero, in steps. Read the induced volts and the revolutions per minute at each step.

4. Make a similar test at a different value of the field current.

Report.—1. Draw neat sketches of the machine, approximately to scale, and give a concise description of the principal parts. If familiar with shop practice, indicate the principal operations necessary for manufacturing these parts.

2. Plot the no-load characteristic at the rated speed and show how to calculate the frequency in cycles per second and in alternations per minute.

3. Prove from your readings that, at a constant field current, the induced voltage is proportional to the speed.

4. Answer the following questions:

(*a*) Why is a direct-current machine usually self-excited while an alternator is not?

(*b*) What is the reason that, in direct-current machines, the armature is always the revolving part while the field is stationary, and that, in alternators, the opposite is usually the case.

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EXPERIMENT E 207–2. VOLTAGE CHARACTERISTICS OF A LOADED ALTERNATOR

Apparatus.—Alternator with a suitable drive; ammeter; voltmeter; field rheostat; load rheostat; choke-coil (load); wattmeter; switch and fuses; speed counter (or tachometer).

The purpose of the experiment is: (*a*) To investigate the influence of the load of an alternator upon its terminal voltage when the field current is kept constant; and (*b*) to find out the increase in the field current required with different loads in order to keep the terminal voltage constant. In other words, this experiment corresponds to experiments E 203–2, " Voltage Characteristics of a Shunt-wound Generator " and E 203–3, " Excitation Characteristics of a Shunt-wound Generator."

In a direct current machine the load is given in amperes, while in an alternator the load is fully determined by the amperes and the power factor. In specifications on the delivery of an alternator, the permissible voltage fluctuation between no load and full load is usually expressed by requiring a certain per cent voltage regulation.

Voltage regulation is defined in this country as the expression

$$100\times\frac{E_0-E_1}{E_1},$$

where E_0 is the no-load voltage of the machine and E_1 is the rated terminal voltage at the rated load. It is assumed that the field current and the speed remain the same between no load and full load. For instance, if the rated voltage of the machine is 2200, and the voltage rises to 2420 when the load is thrown off, the voltage regulation is

$$100(2420-2200)/2200=10 \text{ per cent.}$$

Connections.—The connections for a single-phase alternator are shown in Fig. 1. If a three-phase machine, only, is available, the student is advised to wire up and load one phase only, so as to simplify readings. The relations are qualitatively the same when all the three phases are loaded. While three ammeters are shown in the diagram, it is preferable to use only one ammeter and to transfer it to the three branches by means of a suitable plug-board or switches. Such a plug-board must preferably be so arranged that before a plug connected to the ammeter is completely withdrawn a brass spring closes the circuit, short-circuiting the place of the ammeter.

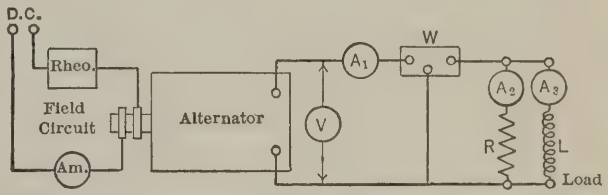


Fig. 1.—Connections for a Single-phase Alternator.

Data Sheet.—A sample data sheet is shown below. The speed must be kept as nearly constant as possible, but unavoidable variations must be recorded.

	Load Amps. Constant at ——— per cent of Full Load Rating.						
	Amperes.			Volts.	Watts.	Field Amps.	Speed.
	Non-Ind.	Ind.	Total.				
Inst. No.							
Const.							

 (over)

Readings.—1. Load the machine at its rated voltage, about 25 per cent overload in rated current, and at the lowest power factor obtainable. Read the quantities indicated in the data sheet. Keep the field current and the total load amperes constant; reduce the inductive amperes and increase the non-inductive amperes so as to increase the power factor of the load. Repeat the readings at each step. Continue this process until all of the inductance is cut out and the load is practically non-inductive. At least eight points are necessary in order to obtain a satisfactory curve.

2. Repeat the same test with the rated current and, if time permits, also at 75 per cent and at 50 per cent of the rating. It must be understood that the field current is kept constant during each set of readings, but that it is different for the different values of the total load current.

3. Adjust the load as under (1); keep the terminal voltage and the load amperes constant, gradually reducing the field current as the power factor of the load increases.

4. Repeat test (3) at the rated current and, if time permits, at 75 per cent and at 50 per cent of the rated current.

5. Take the no-load saturation curve of the machine if one has not been previously obtained (Exp. E 207–1).

Report.—1. Plot curves of terminal volts against per cent power factor when the field current is kept constant. Mark a horizontal straight line indicating the no-load voltage obtainable with the same field current as at the rated load and 100 per cent power factor. This voltage is taken from the no-load saturation curve.

2. Plot values of field current against per cent power factor as abscissæ from the readings when the terminal voltage was kept constant. Mark on the same curve sheet a horizontal straight line indicating the field amperes necessary for the rated voltage at no load. This value is taken from the no-load saturation curve.

3. Plot the no-load saturation curve if it has not been plotted in a preceding experiment.

4. Calculate the per cent voltage regulation at the rated current and a non-inductive load; also for the rated current and an inductive load at the lowest power factor obtainable.

5. If you are familiar with vector diagrams, select a few sets of readings of total amperes and amperes through the resistance and the reactance; construct triangles of currents and check the values of the power factor obtained from the wattmeter readings with those calculated from triangular currents. In Fig. 2 the vectors A_1, A_2, and A_3 represent the three ammeter readings corresponding to Fig. 1. E is the vector of the line voltage. The cosine of the angle marked ϕ represents the power factor; its value must check with the value obtained by dividing the true power as read on the wattmeter by the apparent power which is the product of the terminal voltage times the total load amperes.

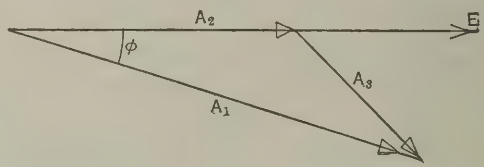


FIG. 2.—Vector Diagram.

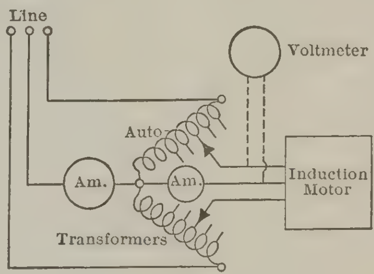
6. Look up the theory of the armature reaction in an alternator and explain the reason why the voltage regulation is poorer at the lower values of the power factor.

EXPERIMENT E 208–1. STARTING AN INDUCTION MOTOR

Apparatus.—Three-phase induction motor; starting transformers; two ammeters; volt meter; Prony brake; stop-watch; three-phase circuit breaker (or switches and fuses).

The purpose of the experiment is to learn the wiring of a three-phase induction motor, to acquire fluency and precision in starting and stopping an induction motor and to investigate the effect of the starting voltage upon the starting torque. In this country, induction motors with a short-circuited or squirrel cage secondary are used almost exclusively, especially in small and medium sizes, and, for this reason, this exercise is limited to motors of this type. To avoid an objectionable rush of current during the first few instants of starting, an induction motor is usually started on a reduced voltage. As soon as the motor has acquired a certain speed it is switched over to the full voltage. In many cases, two or more intermediate voltages are used in succession in order to avoid a sudden change. The intermediate voltages are obtained by means of two auto-transformers connected in V, as shown in the figure. The transformer windings are provided with taps; these taps are connected in succession to the motor terminals. The lowest permissible value of the starting voltage depends upon the required starting torque; the latter decreases approximately as the square of the voltage.

Connections.—The connections are shown in the accompanying diagram. If a regular motor starter is available, it has switches or a controller drum inside by means of which the necessary changes from tap to tap are made. If only two ordinary auto-transformers are available, the student is expected to arrange the switches so as to be able to change from fractional voltages to the full voltage.



Connections for the Test.

Readings.—1. Investigate the behavior of the motor when starting at no load with different taps; vary the time during which the motor is run on a reduced voltage. The problem is to get such a low voltage, such steps, and such intervals of time between the steps as to bring the motor up to its full speed with the least inrush of current from the line. Having the ammeters in the circuit, the student will find the best conditions after several trials. Record volts, amperes and seconds of time for each trial.

2. Make a similar investigation with a definite starting torque, for instance, one quarter of the full-load torque. A load torque may be obtained to a sufficient degree of accuracy by means of a Prony brake. For a description of the latter and the necessary computations, see Experiments E 205–1 and E 205–2 on brake tests of direct-current motors.

3. Repeat the tests with a torque equal to one-half of the full-load torque, and again with three-quarters of the full-load torque. It is probable that, at a torque exceeding this value, an excessive line current would be required for starting.

In performing these experiments, the student must be careful not to overheat the motor and the starting transformers because the apparatus is usually designed for starting at infrequent intervals only.

Report.—Give the numerical results of your tests and specify the exact steps and the duration of each step for the best conditions in starting the motor with various values of the starting torque.

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EXPERIMENT E 208–2. LOAD TEST ON AN INDUCTION MOTOR

Apparatus.—Induction motor with the necessary starting device; ammeter; voltmeter; wattmeter; voltmeter switch; ammeter transfer switch; speed counter; generator to be used as a load; load rheostat for the same; slip meter (desirable but not necessary).

The purpose of the experiment is to obtain performance curves similar to those shown in Fig. 1. Such curves are important for a perspective user of a motor, in order to determine if a motor offered for sale is suitable for his purpose. This experiment ought to be preceded by Experiment E 20 –1, "Starting an Induction Motor." The curve marked "True H.P. Input" is obtained by dividing the watts input to the motor by 746. Similarly, the ordinates of the curve of "Apparent H.P. Input" represent the volt-ampere input divided by 746. The ordinates of the efficiency curve are equal to the ratio of the ordinates of the output and the true input curves. The ordinates of the power-factor curve represent the ratio of true input to apparent input.

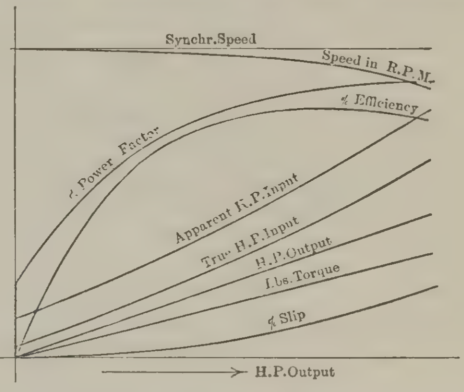

Fig. 1.—Performance Curves of an Induction Motor.

The output of the motor may be measured with a Prony brake in a manner similar to that described in Experiments E 205–1 and E 205–2 on brake tests of direct-current motors. However, in this case the student is advised to calculate the output from the input into the motor and the losses in the motor. This method is preferable because experience shows that it is rather difficult to keep a load constant for any length of time by means of a Prony brake. In the case of a direct-current motor the readings are comparatively simple and can be made in a few seconds. With an induction motor the time necessary for taking readings is much longer (see the data sheet below), and, besides, the motor must be run for at least half a minute or a minute in order to determine its slip accurately. A load consisting of an electric generator, a pump, a blower, etc., may be kept steady for any length of time without much difficulty. Incidentally, this method has the advantage of giving the student some insight into the theory of the induction motor.

Calculation of the Output from the Input and the Losses.—The losses in an induction motor consist of the copper loss in the primary and in the secondary windings, and of the no-load losses (iron loss and friction). The latter can be assumed to be practically constant at all loads and as having the same value as at no load (hence the name "no-load losses"). The primary copper loss can be calculated easily if the primary current and the resistance of the primary winding are known. The secondary copper loss is proportional to the per cent slip, as is shown in the general theory of the induction motor.

Suppose, first, the resistance of the secondary winding to be zero; the slip would be practically zero at any load because the secondary currents necessary for producing a torque could be induced with an infinitesimal difference in speed between the revolving flux and the rotor. If, however, the secondary winding has an appreciable resistance, a certain finite difference in speed is required in order to induce the same torque-producing currents. Thus, the necessary torque is obtained at a sacrifice of a certain per cent of speed. The corresponding loss of output is converted into the I^2R heat in the secondary winding.

The details of the calculation of the output of the motor from its input and the losses may be shown best in a numerical example. A 10 horse-power, 440-volt, 3-phase induction motor

was found to take 800 watts at no load; the no-load current was 5.5. amperes per phase, primary resistance .075 ohm per phase. From these data the iron loss and friction should first be computed; these are equal to 800 watts less a correction for the copper losses in the primary and the secondary windings. But the secondary copper loss is negligible at no load, because the slip is very small. Thus, the correction amounts to $3\times\overline{5.5}^2\times 0.75=68$ watts, and the losses in question are equal to

$$800-68=732 \text{ watts.}$$

Take now a point on the load curve, for instance, corresponding to an input of 15 amperes per phase. Suppose that the power reading at this input was 9920 watts, and the slip 5.4 per cent. The primary copper loss is

$$3\times\overline{15}^2\times 0.75=506 \text{ watts.}$$

Therefore,
output+sec. copper loss$=9920-(506+732)=8682$ watts, the last number representing the input into the secondary.

The secondary copper loss constitutes a part of the input into the secondary, proportional to the per cent slip. Thus, in our case,

$$\text{sec. copper loss}=8682\frac{5.4}{100}=469 \text{ watts.}$$

Therefore,

$$\text{output}=8682-469=8213 \text{ watts}=11 \text{ horse-power.}$$

Knowing the output corresponding to a given input, the efficiency, the torque, and the other quantities shown in Fig. 1 may easily be calculated.

Measuring the Input.—The electrical power input to a three-phase motor is usually measured by the so-called two-wattmeter method, as shown in Fig. 2. One of the line wires, say B, is assumed to be a common return wire for two other wires. The power is measured between the wires A and B, and then between C and B, and the wattmeter readings are added together in order to get the total input to the motor. Accordingly, the series winding of one wattmeter is connected into the line A, and its shunt winding across A–B. The series winding of the other wattmeter is connected into the line C, and the potential winding across C–B. With proper transfer switches only one wattmeter is needed; it is connected in succession in the two positions shown in Fig. 2, and the readings are added algebraically.

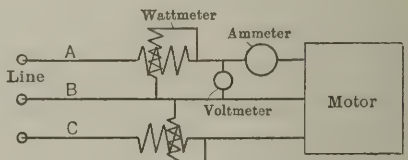

FIG. 2.—Connections for the Test.

Theory and experience show that this method gives correct results for the total power input on balanced as well as on unbalanced loads. However, the two component readings are equal only when the load is balanced and non-inductive (power factor of 100 per cent). In an induction motor the power factor is always less than 100 per cent, so that one of the wattmeter readings is always smaller than the other. On light loads, when the power factor of an induction motor becomes less than 50 per cent, one of the wattmeters begins to give negative deflections. In this case, reverse the potential or the series leads of the meter, and take the *difference* of the two readings instead of their sum.

For this reason it is advisable to begin the test at the maximum load (say 25 per cent overload) where the power factor is surely higher than 50 per cent, and then reduce the load by steps to zero. Then one cannot miss the point at which it becomes necessary to reverse the leads of one of the wattmeters. If a polyphase wattmeter is available, total power is obtained from one reading.

It would hardly be practicable to provide separate ammeters and voltmeters for each phase; a special "polyphase board" or a system of transfer switches is used by means of which the same instruments are connected in succession in the three phases.

Measuring Frequency and Speed.—The method of measuring the speed of an induction motor deserves special attention. The speed depends on the load and on the frequency of the supply currents, as the latter determine the speed of the revolving field. If the power for testing is taken from a commercial supply, the frequency may at times be several per cent above or below the normal, and unless the exact frequency is known at the time when the speed is taken, the speed determination is of little value.

When the generator is accessible, its speed may be measured sumultaneously with that of the motor, so that the two speeds refer to the same frequency. If the generator is not accessible, a small synchronous motor may be run from the same line to which the induction motor is connected. As the speed of the synchronous motor is always equal to that of the generator and automatically follows the variations in speed of the latter, the synchronous motor will give at any moment the actual speed of the generator. Special instruments, so-called frequency meters, may also be used for measuring the frequency of the supply.

Instead of measuring the speed of the motor and the frequency of the supply, it is preferable to measure simultaneously the speed and the slip of the induction motor; their sum gives the synchronous speed, and consequently the frequency of the supplied currents. If, for instance, the motor speed is 702 r.p.m., and the slip 22 r.p.m., the synchronous speed is 724 r.p.m. If the motor is a 10-pole machine, the frequency of the supply is at that particular moment 7240 alternations per minute, instead of the standard 7200. In plotting the speed curve, the corresponding correction must be made.

Slip can conveniently be measured by devices called slip meters. The three principal types of these devices are based on the following principles: stroboscopic, vibrating reed, and rectification of alternating currents. For a detailed description of these devices see V. Karapetoff, Experimental Electrical Engineering, Vol. I, Arts. 340 and 341.

Data Sheet.—The readings may conveniently be recorded in a data sheet similar to the one shown below. If the output is calculated from the losses and no brake is used, the last column is omitted.

	Amperes.			Volts.			Watts.		Speed.		Slip Indic.	Torque.
	A	B	C	AB	BC	CA	A—AB	C—CB	Motor.	Synchr.		Lbs.
Inst. No.												
Const.												

Readings.—1. Wire up the motor as shown in Fig. 2, and, if possible, run it light for at least half an hour in order to obtain a steady condition of the lubrication of the bearings.

2. Begin the test with the heaviest load possible, say about twenty-five per cent above the rating of the motor. Read the quantities indicated in the data sheet, transferring the ammeter, the voltmeter and the wattmeter from phase to phase by means of switches. The readings must be taken very accurately in order to obtain satisfactory curves.

3. Reduce the load in steps and at each step repeat the readings. From eight to ten points are desired on the curves.

4. Take careful readings of amperes and watts at no load.

5. Measure accurately the resistances of the primary windings by the drop-of-potential method, using direct current. Measure by thermometers the temperature of the windings while determining their resistance.

Report.—Calculate the data and plot curves as indicated in Fig. 1. In figuring out the primary copper loss, use the value of the primary resistance at a temperature of 50° C. above the usual temperature of the room.

It should be borne in mind that, when a resistance is measured between two terminals of a Y-connected induction motor, the result thus obtained represents the double resistance per phase. Therefore, in order to obtain the *average* resistance per phase, take the resistance between the terminals A–B, A–C, and B–C, add them together, and divide the result by six.

Plot on a separate sheet, curves of total losses, primary and secondary I^2R losses, and iron loss+friction, against horse-power output as abscissæ, so as to have a clear expression of the relative importance of these losses at various loads.

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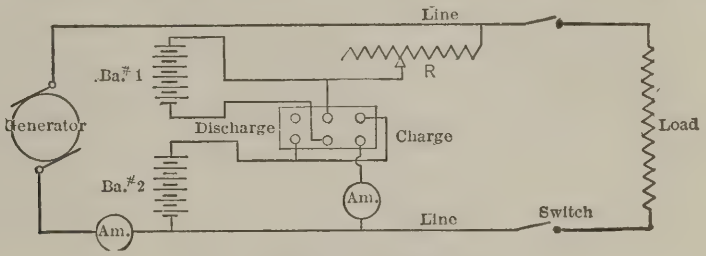
ELECTRICAL TESTING

EXPERIMENT E 209–1. CHARGING A STORAGE BATTERY IN SECTIONS

Apparatus.—A storage battery which may be divided into two or three sections at will; double-pole, double-throw switch; regulating rheostat; two ammeters;* voltmeter; fuses (or circuit breaker).

The purpose of the experiment is to learn methods of charging batteries in sections, without the use of a booster, end-cell switches or other refinements. The methods described below are sufficient for charging small batteries. The experiment ought to be preceded by Experiment E 14–2 on the charge and discharge of a single cell.

The simplest method for charging and regulating a storage battery is shown in the diagram below. The battery is divided into two halves which are connected in series for discharging, and in parallel for charging. This is done in order to secure a sufficient voltage for charging, without affecting the line voltage maintained by the generator. An example will make this clearer. Consider a battery intended for an ordinary 110-volt lighting circuit; the voltage of each cell



Connections for the Experiment.

at the end of discharge is about 1.8 volts, therefore the number of cells required is $110 \div 1.8 = 62$. But the voltage necessary with this number of cells at the end of a charge is $= 2.6 \times 62 = 161$ volts, which is far above the line voltage. With the battery divided into two halves in parallel, only 80.5 volts are required for charge; the excess voltage of the line is taken up by the rheostat R. The battery output on discharge is also regulated by this rheostat. This method, although very simple, is used only in small installations, or where the loss of power in the rheostat is not objectionable.

A more economical method is to divide the battery into three equal parts; let them be denoted A, B and C. The parts A and B are first charged in series for one-half of the time necessary for full charge, then B and C are charged in series for one-half of the time, and finally C and A for one-half of the time. Less energy is wasted in the resistances with this arrangement, although it takes longer to charge the battery. The voltage at the end of the charge is $\frac{2}{3} \times 161 = 107$ volts.

Other combinations are also possible; for instance, A and B may be connected in parallel with each other and in series with C. The set is charged at the full rate until C is completely charged. Then C is disconnected, A and B are connected in series, and the charge is completed.

Order of the Experiment.—Wire up the two halves of a battery, as shown in the diagram, and make connections to a suitable generator. Provide a load in the form of adjustable resistances, and operate the installation under the following conditions:

(*a*) Both the battery and the generator supplying power to the line.
(*b*) The battery being charged, the generator at the same time supplying power to the line.
(*c*) The battery alone supplying power, the generator shut down.
(*d*) The generator working alone, the battery being disconnected for inspection and repairs.

* One of them preferably with zero in the center of the scale.

 (over)

For each of these conditions select a few characteristic loads (light load, medium load, full load and overload) and take all the necessary ammeter and voltmeter readings, so as to have a complete record of the electrical relations in the circuit with special reference to the performance of the battery. Observe the voltage and current fluctuations, when the load is varied, first gradually and then suddenly.

Devise a convenient arrangement of switches for charging the battery in three parts, as explained in the preceding article. Connect the battery accordingly and observe the process of charging.

Report.—1. Draw the exact diagrams of the connections used during the experiment.

2. Give your data in regard to the operation of the installation under conditions (*a*) to (*d*).

3. Compare critically the three methods for charging the battery in sections and give a few rough calculations as to the comparative loss of energy in the regulating rheostat.

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ELECTRICAL TESTING

EXPERIMENT E 210–2. INFLUENCE OF THE TRANSMISSION VOLTAGE AND OF THE CROSS-SECTION OF THE LINE ON ITS REGULATION

Apparatus.—Artificial single-phase transmission line; load rheostat; load reactance coil; ammeter; line voltmeter; low-reading voltmeter; wattmeter; double-throw voltmeter switch; main switch and fuses (or a circuit breaker).

Note.—If the experiment is to be performed with direct-current, omit the reactance coil and the wattmeter.

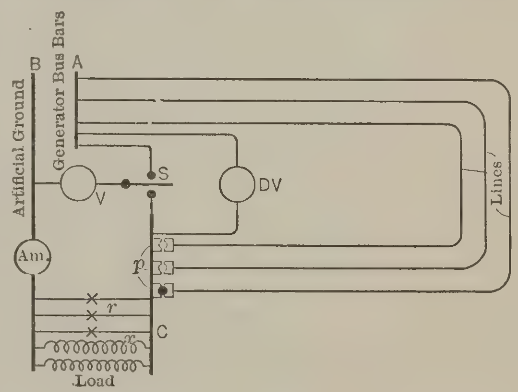
The purpose of the experiment is to illustrate the influence of some of the factors which determine the size of the conductor used in a long-distance transmission line. Some other factors are discussed in the companion leaflet E 210–1 "Influence of Load and of Distance of Transmission on Voltage Regulation of a Line."

With a given generator voltage the voltage at the receiver end is determined by the voltage drop in the line. But this voltage drop depends upon the following factors: (*a*) the resistance of the line conductors per mile; (*b*) the reactance of the line conductors per mile; (*c*) the capacity of the line (which is neglected in these experiments); (*d*) the length of the line; (*e*) the magnitude of the load; (*f*) the power factor of the load. In order to give a satisfactory service the voltage drop must not exceed a certain percentage of the normal receiver voltage; otherwise, individual customers would be annoyed by the voltage fluctuations at the terminals of their lamps and motors caused by the load fluctuations of other customers. In this country per cent voltage regulation is defined as

$$100 \times \frac{E_0 - E_1}{E_1},$$

where E_0 is the receiver voltage at no load, and E_1 is the receiver voltage at the rated load, the generator voltage remaining constant.

When the load on a given line has grown to such a magnitude that the voltage drop is too large for a satisfactory service, there are usually two ways out of the difficulty; either to increase the cross-section of the conductors or to raise the transmission voltage. The purpose of this experiment is to study the influence of these two factors (cross-section of the conductor and the transmission voltage) upon voltage drop and regulation.



Connections.—The diagram of connections is shown in the figure. It is not necessary to have a transmission line strung in the laboratory. All that is needed is a resistance and a reactance in series with it which to a certain scale represent those of an actual line.* Moreover, it is sufficient to have the resistance and the reactance of the two conductors of a single-phase line concentrated in one, and to replace the other conductor by an ideal one without resistance or reactance (artificial ground). The advantage of such an arrangement is that the whole drop is concentrated upon one conductor and may be measured directly with the low-reading voltmeter D.V. (drop voltmeter). Three separate lines are shown in the diagram, which may differ from one another in their electrical characteristics. Any of the three may be used by simply chang-

* For actual values of resistances and reactances of transmission lines consult tables in various electrical handbooks, pocket-books, and treatises on power transmission.

(over)

ing the position of the plug p. The voltmeter V measures both the generator and the receiver voltages by means of the switch S. In a direct-current line the voltage drop in the line is the arithmetical difference of the generator and the receiver voltages; but in an alternating-current line the three voltages are not in phase, so that the voltage drop is larger than the arithmetical difference between the generator and the receiver voltage.

A variable generator voltage required in this problem may be obtained in one of the following ways: (*a*) by using a separate generator which may be excited at will; (*b*) by connecting a resistance in series with the line, so as to cut down the available voltage; (*c*) with alternating currents the most convenient way is to use a transformer or auto-transformer with several taps on the windings.

Data Sheet.—Record load amperes, watts, and volts; generator volts; and the voltage drop in the line. Also note the resistance and the reactance of the line.

Readings.—1. Begin the experiment with the most unfavorable conditions, that is, a line of minimum cross-section possessing a maximum resistance and reactance, the lowest generator voltage, the heaviest load, and the lowest power factor.

2. Repeat the test with a non-inductive load.

3. Keep the generator voltage and the load the same as in the preceding two tests, and use lines of larger cross-section. In adjusting the resistance and the reactance, remember that when the cross-section of a conductor is doubled its resistance is reduced to one-half, but the reactance of the line, with the same spacing, may be reduced only a few per cent.

4. Use the same watts load and the same line as in the first two experiments, but raise the generator voltage in steps, taking readings at each step.

Report.—1. Plot curves or tabulate your results showing how the regulation is improved and the line drop reduced by using larger size conductors.

2. Plot similar curves showing the effect of the transmission voltage, at a constant load.

3. Answer the following questions:

(*a*) Why are higher voltages used for longer transmission lines and vice versa?

(*b*) What would you do in a given case to improve the regulation of a line, raise the transmission voltage or increase the cross-section of the conductors? Mention some arguments in favor of and against each solution.

(*c*) The conductivity of aluminum is about 62 per cent of that of copper, and its specific weight is about 30 per cent of that of copper. If copper costs 15 cents a pound, what must be the maximum cost of aluminum per pound in order that an aluminum transmission line be at least as cheap as that made of copper? Both lines must have the same resistance per mile.

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EXPERIMENT E 210–2. INFLUENCE OF THE TRANSMISSION VOLTAGE AND OF THE CROSS-SECTION OF THE LINE ON ITS REGULATION

Apparatus.—Artificial single-phase transmission line; load rheostat; load reactance coil; ammeter; line voltmeter; low-reading voltmeter; wattmeter; double-throw voltmeter switch; main switch and fuses (or a circuit breaker).

Note.—If the experiment is to be performed with direct-current, omit the reactance coil and the wattmeter.

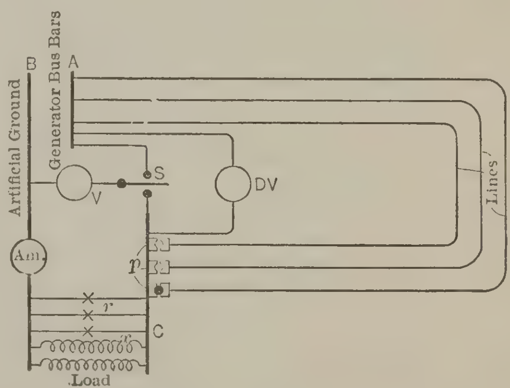
The purpose of the experiment is to illustrate the influence of some of the factors which determine the size of the conductor used in a long-distance transmission line. Some other factors are discussed in the companion leaflet E 210–1 "Influence of Load and of Distance of Transmission on Voltage Regulation of a Line."

With a given generator voltage the voltage at the receiver end is determined by the voltage drop in the line. But this voltage drop depends upon the following factors: (*a*) the resistance of the line conductors per mile; (*b*) the reactance of the line conductors per mile; (*c*) the capacity of the line (which is neglected in these experiments); (*d*) the length of the line; (*e*) the magnitude of the load; (*f*) the power factor of the load. In order to give a satisfactory service the voltage drop must not exceed a certain percentage of the normal receiver voltage; otherwise, individual customers would be annoyed by the voltage fluctuations at the terminals of their lamps and motors caused by the load fluctuations of other customers. In this country per cent voltage regulation is defined as

$$100\times\frac{E_0-E_1}{E_1},$$

where E_0 is the receiver voltage at no load, and E_1 is the receiver voltage at the rated load, the generator voltage remaining constant.

When the load on a given line has grown to such a magnitude that the voltage drop is too large for a satisfactory service, there are usually two ways out of the difficulty; either to increase the cross-section of the conductors or to raise the transmission voltage. The purpose of this experiment is to study the influence of these two factors (cross-section of the conductor and the transmission voltage) upon voltage drop and regulation.



Connections.—The diagram of connections is shown in the figure. It is not necessary to have a transmission line strung in the laboratory. All that is needed is a resistance and a reactance in series with it which to a certain scale represent those of an actual line.* Moreover, it is sufficient to have the resistance and the reactance of the two conductors of a single-phase line concentrated in one, and to replace the other conductor by an ideal one without resistance or reactance (artificial ground). The advantage of such an arrangement is that the whole drop is concentrated upon one conductor and may be measured directly with the low-reading voltmeter D.V. (drop voltmeter). Three separate lines are shown in the diagram, which may differ from one another in their electrical characteristics. Any of the three may be used by simply chang-

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A variable generator voltage required in this problem may be obtained in one of the following ways: (*a*) by using a separate generator which may be excited at will; (*b*) by connecting a resistance in series with the line, so as to cut down the available voltage; (*c*) with alternating currents the most convenient way is to use a transformer or auto-transformer with several taps on the windings.

Data Sheet.—Record load amperes, watts, and volts; generator volts; and the voltage drop in the line. Also note the resistance and the reactance of the line.

Readings.—1. Begin the experiment with the most unfavorable conditions, that is, a line of minimum cross-section possessing a maximum resistance and reactance, the lowest generator voltage, the heaviest load, and the lowest power factor.

2. Repeat the test with a non-inductive load.

3. Keep the generator voltage and the load the same as in the preceding two tests, and use lines of larger cross-section. In adjusting the resistance and the reactance, remember that when the cross-section of a conductor is doubled its resistance is reduced to one-half, but the reactance of the line, with the same spacing, may be reduced only a few per cent.

4. Use the same watts load and the same line as in the first two experiments, but raise the generator voltage in steps, taking readings at each step.

Report.—1. Plot curves or tabulate your results showing how the regulation is improved and the line drop reduced by using larger size conductors.

2. Plot similar curves showing the effect of the transmission voltage, at a constant load.

3. Answer the following questions:

(*a*) Why are higher voltages used for longer transmission lines and vice versa?

(*b*) What would you do in a given case to improve the regulation of a line, raise the transmission voltage or increase the cross-section of the conductors? Mention some arguments in favor of and against each solution.

(*c*) The conductivity of aluminum is about 62 per cent of that of copper, and its specific weight is about 30 per cent of that of copper. If copper costs 15 cents a pound, what must be the maximum cost of aluminum per pound in order that an aluminum transmission line be at least as cheap as that made of copper? Both lines must have the same resistance per mile.

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ELECTRICAL TESTING

EXPERIMENT E 211-1. STARTING SYNCHRONOUS MOTORS

Apparatus.—Synchronous motor; direct-current motor for bringing it up to speed; main ammeter; voltmeter; field ammeter; field rheostat; synchronizing lamps; main switch; fuses (or preferably a circuit breaker); field switch and fuses; a power-factor meter is desirable but not necessary.

The purpose of the experiment is to learn the usual methods of starting and synchronizing a synchronous motor, and to acquire some skill in so doing. Before a synchronous motor can be connected to the line and furnish mechanical power, the line voltage and that induced in the motor must fulfil three conditions: (1) They must be nearly equal numerically; (2) they must be of the same frequency; (3) they must be *in phase* with one another. The process of bringing a synchronous machine in phase with another or with the line is called *synchronizing* (bringing in step).

Action of a Synchronous Motor.—The action of a synchronous motor may be explained as follows: Suppose the machine to be single-phase and to be brought up to the required speed by some other motor. Assume that at a certain moment the relative position of the pole-pieces and of the armature winding is such that the winding attracts the pole-pieces. As the machine is supposed to revolve synchronously, the pole-pieces change their position during one alternation of the supply current by one pole pitch, so that the north poles come in place of the south poles, and vice versa. At the same time the direction of the armature current is reversed, so that the mutual force between the two is again attraction and not repulsion.

Another explanation limited to the case of polyphase synchronous motors is that the polyphase armature winding produces a revolving magnetic field which rotates synchronously in the air-gap. The field poles of the machine must revolve at the same speed in order that there be a constant attraction between the two magnetic fields; otherwise south poles and north poles are brought together in succession and the resultant attractions and repulsions neutralize each other.

Starting Synchronous Motors.—The above explanation of the action of the synchronous motor shows that it must be started and brought up to full speed before being capable of carrying a load. The following means are used for starting synchronous motors: (1) A small induction motor, mounted on the same shaft with the synchronous motor, belted, or geared to it. (2) If a source of direct current is available, the exciter machine belted or directly connected to the motor, is sometimes used for starting. (3) The synchronous motor itself (if polyphase) is converted into an induction motor and started as such.

Synchronizing Lamps.—In order to ascertain when the first of the above-named three conditions is fulfilled, a voltmeter is used, which is connected in succession across the line and across the terminals of the motor. The second condition is approximately fulfilled when the machine is running at its rated speed.

In order to ascertain when the third condition is fulfilled, incandescent lamps (Fig. 1) are connected across the switch between the motor and the line. As long as the motor is not in phase with the line, equalizing currents circulate through it, and the lamps a serve both to reduce and to indicate these currents. By varying the speed of the machine, it is possible to extinguish the lamps; this will show that the machine is in perfect synchronism, and the switch can be closed. The sketch illustrates the case of a three-phase machine; with a single-phase machine one of the lines, say CC_1, is omitted.

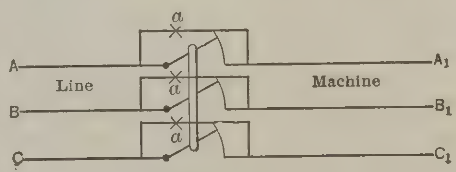

Fig. 1.—Synchronizing Lamps Connected Across the Motor Switch.

Some prefer to have synchronizing lamps crossed, as shown in Fig. 2. The machine is in synchronism when the lamps glow the brightest. As an advantage of this arrangement, it is claimed that a lamp should burn out during the process of synchronizing, the operator would immediately notice it, while with the first arrangement he may judge, by the lamps being extinguished, that the machine is in perfect synchronism. Thus, he may close the switch while the machine is altogether out of phase, and, unless the protective devices (fuses or circuit breakers) operate promptly, the machine may be damaged by the rush of current. However, the possibility of a synchronizing lamp burning out is rather remote, and, with two- or three-phase machines, the burning out of one set of lamps would not affect the others. On the other hand, it is generally considered that it is easier to observe moments of total extinguishing than moments of maximum brilliancy.

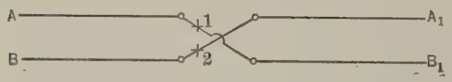

FIG. 2.—Synchronizing Lamps Crossed.

With three-phase machines, crossing synchronizing lamps in two phases is very convenient, especially when the lamps are arranged in a circle, as in Fig. 3. In this case, maximum brightness occurs in the three sets of the lamps in rotation, so that the light appears traveling along the circle. The direction in which the light rotates depends on whether the speed of the machine is low, or high. When the machine is in synchronism, the lamps marked "3" are dark, while the lamps "2" and "1" glow brightly.

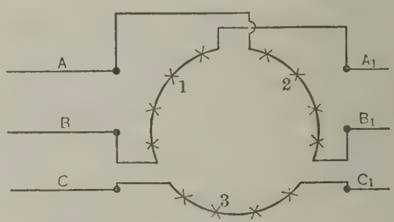

FIG. 3.—Synchronizing Lamps Crossed in Two Phases.

If a 220-volt single-phase motor is to be synchronized, at least four 110-volt synchronizing lamps should be used in series, because at certain moments during synchronizing the e.m.fs. of the machines may be acting in the same direction instead of in opposition, thus giving 440 volts. It is even better to have 5 lamps in series, so as not to let them glow too brightly; it is easier to observe the periods of the extinguishing of the light. With two three-phase machines of the same voltage, the pressure across the lamps in each phase can never exceed 220 volts, so that two 110-volt lamps in series are sufficient, though three lamps may give a better service.

In synchronizing three-phase machines, lamps must always be provided in at least two phases. It is not sufficient to have the lamps in one phase only, because when phase A is connected to A_1 phase, B may be connected to C_1 and C to B_1, thus causing a partial short-circuit.

Ordinary voltmeters may be used for synchronizing, instead of lamps; a voltmeter can be safely connected between the machines because of its high resistance. When the machines are in synchronism, the voltmeter pointer comes to zero; otherwise it swings to and fro.

During the last few years, synchronizing lamps have gradually given place to special synchronizing instruments, so-called synchroscopes, or synchronism indicators. These devices have the appearance of ordinary switchboard instruments, except that the pointer has no retaining spring or weight, and is free to revolve through 360 degrees. When the speed of the alternator to be synchronized is low, the pointer revolves in one direction; if it is high the pointer rotates in the opposite direction. When the speed is right, the pointer stands still; and when the machine is "in phase," the pointer shows zero, indicating that the main switch may be closed.*

Connections.—The armature of the motor is connected to the line with synchronizing lamps placed across the switch. In addition to this switch, it is advisable to have an overload circuit breaker which would protect the motor should the synchronizing switch be closed at a wrong instant. Have an ammeter in one of the phases and a voltmeter across one of the phases of the machine. The line voltage can be measured once for all before the beginning of the experiment. The field winding of the motor is connected to a source of direct current, in series with an ammeter, a rheostat and a switch.

* The same methods are used in synchronizing alternators and rotary converters.

Order of the Experiment.—1. Knowing the frequency of the supply and the number of poles of the motor calculate its required speed. For instance, if the frequency of the supply is 50 cycles per second, and the number of poles is 6, we reason as follows: There are two alternations or one cycle per pair of poles; hence, three cycles per one revolution of the machine. The frequency is $50\times60=3000$ cycles per minute, consequently the required number of revolutions per minute is $3000/3=1000$. Bring the motor to this speed by means of the available drive.

2. Excite the field so that the induced voltage is nearly equal to the line voltage. The lamps are now flickering.

3. Regulate the speed of the motor until the lamps show almost a perfect synchronism, that is they light up and grow dim *slowly*. Close the switch at the right moment; do not be in a hurry, but act decisively when you are ready. Disconnect the drive from its source of power, or throw off the belt to convince yourself that the motor is running from the alternating-current supply. Apply some mechanical pressure to its pulley in order to see that the motor is capable of carrying a load.

4. Try different methods of synchronizing, that is with the lamps dim, bright, and the light revolving, according to Figs. 1, 2, and 3.

5. Try synchronizing with a voltmeter, and with a synchronism indicator, if one is available.

6. Decide upon the best conditions for synchronizing and then synchronize the motor several times in succession, starting every time with the motor at rest and with no field. Make a note of the least number of seconds during which you succeeded in synchronizing the machine and making it ready for the load. Promptness in synchronizing is of great practical consequence when a synchronous machine carries an important load.

7. See what effect is produced if the motor is switched in without having some one of the three above-mentioned conditions fulfilled. This produces a partial short-circuit; therefore be sure that the machine is protected by a reliable circuit breaker.

8. After the motor has been synchronized, increase the field current above the normal, and then reduce it below the normal. You will find that in either case the current taken from the line is increased. Since the losses in the machine are practically the same, the additional current must be wattless (reactive). Theory and experiment show that, when a synchronous motor is over-excited, it draws a leading current from the line. This relation is often used in order to improve the power factor of the load. An under-excited synchronous motor draws a lagging current from the line, which is usually undesirable. If a power-factor meter is available, the existence of the lagging or leading currents, depending upon the excitation, may be shown directly. If not, connect reactance coils between the switch and the motor, one in each phase; adjust the reactances so that 10 to 20 per cent of the line voltage is consumed in them. Measure the motor voltage with the field under-excited and over-excited. It will be found that in the first case the motor voltage is below that of the line, in the second case it is higher than the line voltage. But, from the general theory of alternating currents, it is known that a leading current through a reactance causes a negative drop, in other words the line voltage is increased.

9. If the drive is a direct-current, shunt-wound motor, an interchange of power between the two sources of power supply may be arranged. Having synchronized the alternating-current motor, raise the excitation of the direct-current motor. Its counter-e.m.f. becomes larger than that of the line and it begins to act as a generator, "pumping" power into the direct-current line at the expense of the power delivered from the alternating-current line. The direct-current line ammeter shows a reversed current. Now weaken the field of the direct-current machine below normal. In its tendency to run faster it drives the alternating-current motor so that the latter begins to "pump" power into the alternating-current line, acting as an alternator. Having an indicating wattmeter in the alternating-current line, this reversal in the sign of power can be observed directly. Having measured the watts output of one machine and the input into the other machine, the efficiency of the set can be calculated. Take such readings with either machine working as a generator.

Report.—1. Give the exact diagrams of the connections used.

2. Give detailed instructions for synchronizing under the conditions which you have

found to be the best, and state how many seconds it takes to synchronize under these conditions.

3. Describe what happened when the machine was switched in without being brought to exact synchronism.

4. State how you proved the existence of lagging and leading currents in the armature, and give theoretical reasons for their existence.

5. Show how to calculate the efficiency of the set from the input and the output, and give your data and results.

EXPERIMENT E 212-1. ASSEMBLING AND OPERATING A DIRECT-CURRENT SWITCHBOARD

Apparatus.—As per Fig. 2, or Fig. 3.

The purpose of the experiment is to become acquainted with the arrangement of apparatus

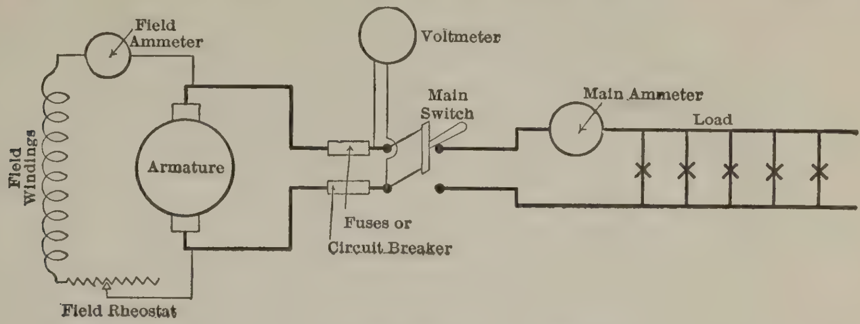

FIG. 1.—Connections for the Generator.

on small and medium-sized switchboards used in connection with direct-current generators, for instance in isolated power plants.

One Generator.—With one generator (Fig. 2) the connections are practically the same as in Fig. 1, already familiar to the student from the experiments on characteristics of direct-current generators, except that in practice the field ammeter and the field switch are usually omitted. The ammeter and the voltmeter are mounted near the top of the switchboard; between them is visible the handle of the field rheostat. The large switch in the center connects the machine to the switchboard; the four smaller switches are for the outgoing feeders. All the connections are made on the back of the switchboard. The little circles shown on each side of the instruments denote ground-detector lamps. Each lamp is connected between one terminal of the machine and the ground (for instance a water pipe). As long as the insulation of the machine is good, the lamps are dark, but when one side becomes grounded, the lamp on the other side lights up. Each switch circuit is protected by fuses, visible under the switches. Automatic circuit breakers are coming more and more into use instead of switches and fuses. The main switch is connected on the back to two horizontal copper bars, commonly called *bus-bars*, so that the generator power is delivered to the bus-bars. The feeder switches are also connected to the bus-bars, and in this way the energy taken from the generator is delivered to various feeder circuits.

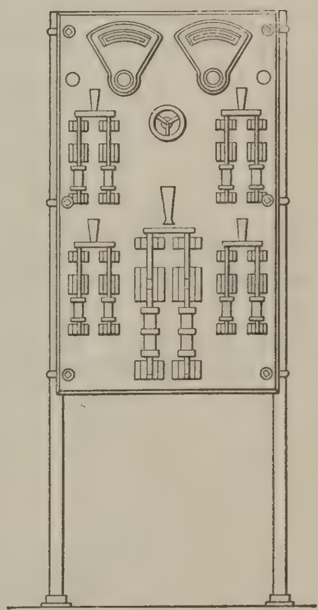

FIG. 2.—Switchboard for a Single Generator.

Two Generators.—Switchboard connections for two compound-wound generators are shown in Fig. 3. The two outside panels are generator panels. The middle panel is for the outgoing feeders. The left-hand panel is shown with all the connections; the right-hand panel is left unconnected. The main bus-bars extend throughout the whole length of the switchboard. The negative terminals of the machines are connected directly to the negative bus-bar, through the main switches. The positive cables are connected to the corresponding bus-bar, through the circuit breakers and the ammeters. One terminal of each field circuit is taken to the switchboard,

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in order to have it connected to the field rheostat. One voltmeter is used for both machines. It may be connected to either machine by means of a receptacle and a plug. Each generator panel is provided with a lamp which serves for illuminating the ammeter scale and also as a pilot lamp.

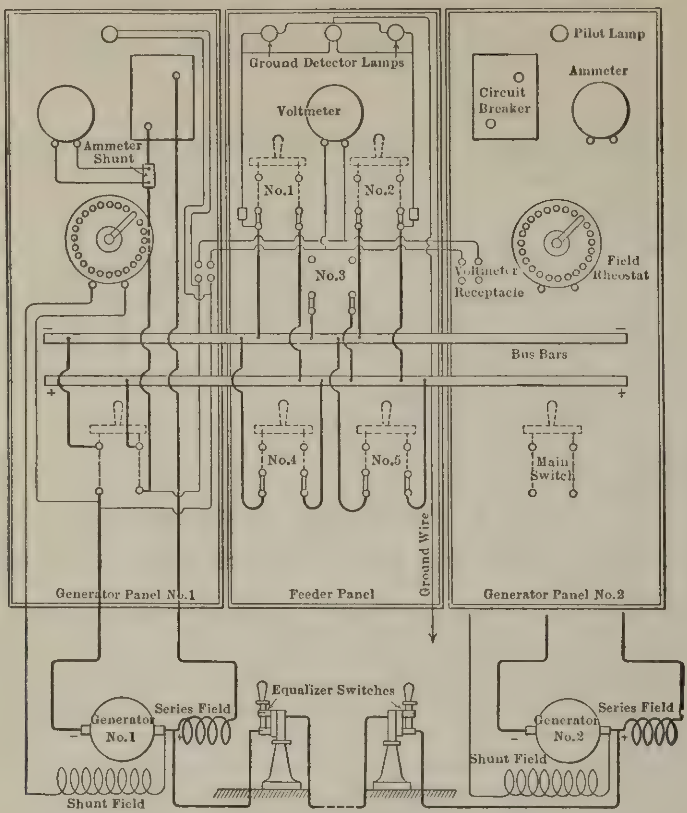


Fig. 3.—Switchboard Connections for Two Compound-wound Generators.

The feeder panel has three lamps on top. The middle one is connected across the bus-bars and illuminates the voltmeter scale; the two outside ones are ground-detector lamps. Five feeder switches are shown on the middle panel, each circuit being protected by fuses. Circuit breakers, taking the place of both fuses and switches, are much used at present.

The equalizing connection shown between the positive brushes of the machines is used with compound-wound generators only, its purpose being to make the two machines divide the load equally. The action of the equalizer is as follows: suppose (Fig. 4) that for some reason the induced e.m.f. of machine No. 2 is higher and therefore the current supplied by it larger than that of machine No. 1. This tends to make the ohmic drop between a_2 and b_2 larger than that between a_1 and b_1; but, with an equalizing cable of a negligible resistance between a_1 and a_2, this is impossible, and thus part of the current of machine No. 2, instead of flowing from a_2 to the positive bus-bar directly through b_2, flows to the same bus-bar through the equalizer c and the series winding of machine No. 1. Therefore, the field of machine No. 2 is strengthened *less* than it would be without the equalizer; at the same time the field of the weaker machine, No. 1, is strength-

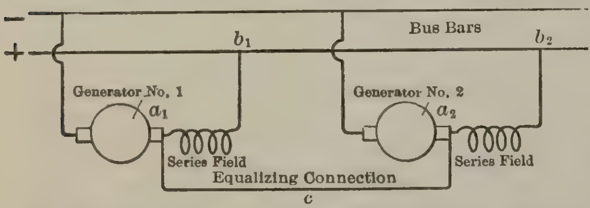


Fig. 4.—Equalizing Connection for Compound-wound Generators.

ened by the excess of the current of the other machine; machine No. 1 is thus helped to keep up its voltage. In short, *the equalizing connection prevents the currents in the series fields of two or more machines from differing widely from each other, however different their armature currents may be.* Therefore, when connected by an equalizing bus-bar, different machines cannot have widely different voltages, cannot easily have the load disproportionately distributed, and the more remote becomes the possibility of one machine pumping power back into the other machine.

The Wiring.—Much of the benefit derived from this experiment depends upon a neat wiring on the back of the switchboard. For experimental purposes the switchboard itself may consist simply of a few wooden boards, with holes drilled to receive the studs of the instruments and the switches. First, place two bus-bars on the back, supporting them from simple brackets properly insulated. Then wire up the main circuit, and finally the voltmeter connections, ground detectors, etc. Then connect the machine (or machines) to the switchboard.

Operating the Switchboard.—Imagine yourself to be a switchboard operator in an isolated power plant, and perform the operations which he would have to perform under normal conditions.

1. In a plant with one generator only, start the machine, excite it properly, close the main switch, and finally load it. Then perform the operations necessary for shutting down the plant.

2. Operate the plant with two shunt-wound machines in parallel, transferring the load at will from one machine to the other by regulating the field rheostats. Start for instance with machine No. 1, have it loaded, then connect No. 2 in parallel, divide the load equally, transfer the load to No. 2, and disconnect No. 1.

3. If conditions permit, operate two compound-wound machines in parallel, with and without an equalizing connection, so as to see the purpose of such a connection.

Report.—1. Draw a neat diagram of the actual connections if different from those shown in Figs. 2 and 3.

2. Write explicit and concise directions as to the order in which operations must be performed when starting the plant, paralleling the machines, changing the load from one machine to the other, and shutting down.

3. Show how to calculate the size (rating in amperes) of the switches, ammeters, and conductors in a plant of a given size. Assume the permissible overload to be 25 per cent.

ELECTRICAL TESTING

EXPERIMENT E 213-1. TEST OF A LIFTING MAGNET

Apparatus.—Suitable electromagnet; iron or steel armature for the same; ammeter; regulating rheostat; weights.

The purpose of the experiment is to determine the relation between the current consumed by an electromagnet, under different conditions of service, and its lifting power. The theoretical formula for the mechanical force, F, of attraction between the core and the armature is

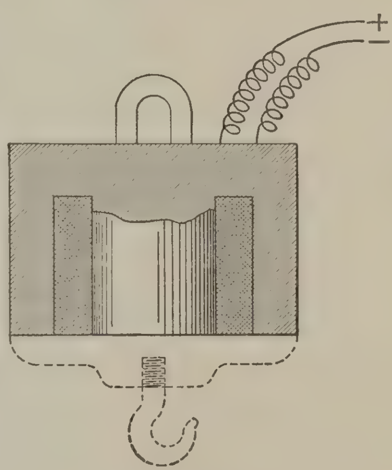
$$F=\frac{\mathbf{B}^2 A}{72.13}\text{ lbs.,}$$

where **B** is the magnetic flux density in the air-gap, in kilolines per square inch, and A is the total area of contact between the armature and the iron core, in square inches. This includes the inner area and the concentric outer area. In the metric system

$$F=\frac{\mathbf{B}^2 A}{24.65}\text{ kgr.,}$$

where **B** is in kilolines per square centimeter, and A is the area in square centimeters. It will be seen from these expressions that the lifting power increases as the square of the flux density in the air-gap. Without saturation in iron, the flux density would be proportional to the exciting current, and the lifting power would be proportional to the square of the current. However, as saturation sets in, the lifting power increases more slowly than the square of the current.

The flux density, at a certain current, depends upon the reluctance (magnetic resistance) of the paths of the lines of force. Consequently, by interposing a sheet of paper or fiber between the core and the armature, the lifting power is considerably reduced. The same effect is produced when the surface of the object to be lifted is irregular and touches the core only in a few points. Again, by substituting a cast-iron armature in place of a steel one, the reluctance of the magnetic circuit is increased and the lifting power of the magnet is reduced. The magnet may be loaded by suspending weights directly on the hook of the armature, but it is sometimes more convenient to introduce a leverage. The magnet is made to pull upward on the short arm of a lever, and a comparatively small weight is suspended at the end of the long arm. In this way one need not handle large weights. The pull is to the weight as the inverse ratio of the arms.



Lifting Magnet.

Data Sheet.—Record exciting amperes, and the weights which are necessary in order to pull the armature from the core. The weight of the armature must, of course, be included.

Readings.—1. Excite the armature with the highest available current, or that which is safe for the winding. Load the armature until it drops. Note the current and the weight used. Reduce the current, and repeat the test, etc. From eight to ten points are necessary for a good curve. Having reduced the current, do not increase it again; otherwise you will be following a different hysteresis loop (see experiment E 201-1). Having reduced the current to zero, repeat the test with an increasing current so as to see the influence of the residual magnetism.

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2. Repeat the test, using a definite thickness of paper or fiber between the armature and the core.

3. Repeat the test using a different armature, for example one made of cast iron if the first one was of cast steel. Before leaving the laboratory weigh the armature used.

Report.—1. Plot the lifting power in pounds or in kilograms to amperes as abscissæ. Use the same curve sheet and the same scale for all the curves so as to make a direct comparison possible.

2. Indicate by dotted lines one or two theoretical curves which would obtain if the lifting power continued to increase indefinitely as the square of the current (parabola).

3. For a certain excitation which is assumed to be normal or rated for the magnet, tabulate the corresponding flux densities with the two armatures used, and when a layer of non-magnetic material was interposed; use the formula given above, solving it for **B**.

4. Answer the following questions:

(*a*) Why are lifting magnets made with a closed magnetic circuit resembling a horseshoe magnet rather than a bar magnet?

(*b*) To obtain a given lifting power with a given core, a certain number of ampere-turns is necessary. What determines the number of turns and the current in practice, seeing that only the product of these two quantities is given?

(*c*) In what cases would you use a lifting magnet in preference to an ordinary hook, in connection with a traveling crane?

EXPERIMENT E 213-1. TEST OF A LIFTING MAGNET

Apparatus.—Suitable electromagnet; iron or steel armature for the same; ammeter; regulating rheostat; weights.

The purpose of the experiment is to determine the relation between the current consumed by an electromagnet, under different conditions of service, and its lifting power. The theoretical formula for the mechanical force, F, of attraction between the core and the armature is

$$F=\frac{\mathrm{B}^2A}{72.13}\ \text{lbs.},$$

where **B** is the magnetic flux density in the air-gap, in kilolines per square inch, and A is the total area of contact between the armature and the iron core, in square inches. This includes the inner area and the concentric outer area. In the metric system

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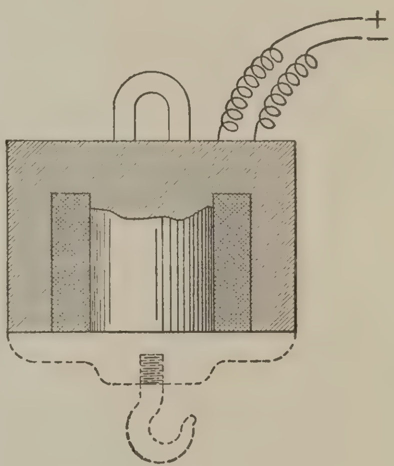

Lifting Magnet.

Data Sheet.—Record exciting amperes, and the weights which are necessary in order to pull the armature from the core. The weight of the armature must, of course, be included.

Readings.—1. Excite the armature with the highest available current, or that which is safe for the winding. Load the armature until it drops. Note the current and the weight used. Reduce the current, and repeat the test, etc. From eight to ten points are necessary for a good curve. Having reduced the current, do not increase it again; otherwise you will be following a different hysteresis loop (see experiment E 201-1). Having reduced the current to zero, repeat the test with an increasing current so as to see the influence of the residual magnetism.

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2. Repeat the test, using a definite thickness of paper or fiber between the armature and the core.

3. Repeat the test using a different armature, for example one made of cast iron if the first one was of cast steel. Before leaving the laboratory weigh the armature used.

Report.—1. Plot the lifting power in pounds or in kilograms to amperes as abscissæ. Use the same curve sheet and the same scale for all the curves so as to make a direct comparison possible.

2. Indicate by dotted lines one or two theoretical curves which would obtain if the lifting power continued to increase indefinitely as the square of the current (parabola).

3. For a certain excitation which is assumed to be normal or rated for the magnet, tabulate the corresponding flux densities with the two armatures used, and when a layer of non-magnetic material was interposed; use the formula given above, solving it for **B**.

4. Answer the following questions:

(*a*) Why are lifting magnets made with a closed magnetic circuit resembling a horseshoe magnet rather than a bar magnet?

(*b*) To obtain a given lifting power with a given core, a certain number of ampere-turns is necessary. What determines the number of turns and the current in practice, seeing that only the product of these two quantities is given?

(*c*) In what cases would you use a lifting magnet in preference to an ordinary hook, in connection with a traveling crane?

ELECTRICAL TESTING

EXPERIMENT E 214-1. OPERATING MOTOR STARTERS WITH NO-VOLTAGE AND OVERLOAD RELEASE

Apparatus.—One or more motor-starters and speed regulators with automatic no-voltage and overload features; shunt-wound motor; ammeter; voltmeter; switch and fuses.

The purpose of the experiment is to acquaint the student with the principal types of starting and regulating devices used in practice in connection with direct-current motors. Small motors are usually operated and taken care of by persons of limited electrical training, and the rheostats must be designed to meet the severe conditions of usage. It is impossible in a limited space to give a description of various types of starting and regulating rheostats with automatic protective features used in practice. With a little experience the construction and the functions of a given device are easily ascertained. To assist the student, his attention is called to the principal requirements in the operation of shunt-wound motors; these requirements will be found incorporated in motor starters and regulators with which he will be called upon to deal.

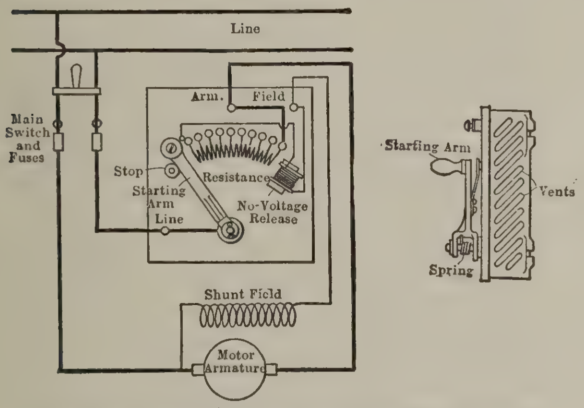

Fig. 1.—Motor Starter with No-voltage Release.

(1) **No-voltage Release** (Fig. 1).—One fundamental requirement which every motor starter must satisfy is that its whole resistance must be automatically introduced in series with the motor armature as soon as the main-switch is opened or the power is "off" for any reason whatsoever. Otherwise, when the power is "on" again, or the main switch is carelessly closed, a current would flow through the armature equal to many times its rated current. The result would be that either the fuse would blow out, or the circuit breaker would not stay "in"; it is also possible that damage would be done to the motor. Therefore, the operating handle of a motor starter is held in its running position by the attraction of an electromagnet energized from the line. Should the power be "off," the electromagnet is de-energized, the handle is released, and it flies back to its starting position under the action of a spring. The coil of the electromagnet is connected to the line either directly or in series with the shunt field winding of the motor. In the latter case it protects the motor if the field circuit is broken, even though the power is still on.

(2) **Overload Release.**—A motor circuit can be protected by a circuit breaker or fuses like any other circuit. But when the conditions of the service are such that the motor is frequently overloaded, fuses are unsuitable, being expensive and causing delays. A circuit breaker can be incorporated into one apparatus with the motor starter. The advantages of this arrangement are that the combined apparatus costs less, and the attendant has only one handle to operate, so that he cannot perform the operations in a wrong order. There are two principal types of motor starters with an overload feature. In the simplest type a small electromagnet is provided, the coil of which is connected in series with the line. When the current through the

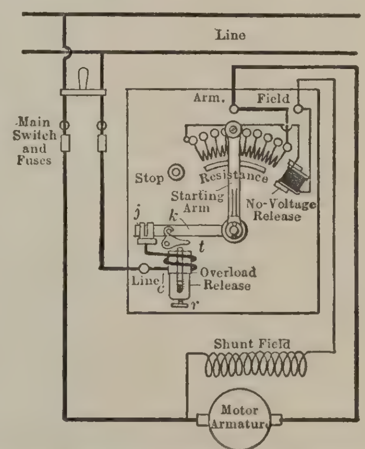

Fig. 2.—Motor Starter with No-voltage and Overload Release.

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motor exceeds a certain limit, this electromagnet attracts its armature. The latter strikes a contact which short-circuits the coil of the no-voltage release magnet described under (1) above. The starting handle is released and the motor stopped. In the other type (Fig. 2) the overload release electromagnet c holds a separate blade, k, which, on an overload, is released by the latch t, flies off and forms one lever with the starting arm. To start the motor again, it is necessary to return the starting lever to its starting position, because in this position the blade k closes the main circuit at j and is held by the overload electromagnet. The knurled head r is for the purpose of adjusting the overload electromagnet to trip at a desired value of the current. The second type is more positive in its action, but is somewhat more expensive.

(3) **Field Control.**—In the above-described starting rheostats, no provision is made for regulating the field current of the motor, in other words, for varying its speed. If speed control is required, an additional rheostat must be connected into the field circuit. But it must be remembered that the motor should always be started with the strongest field, in order to get a good starting torque without an excessive rush of current. Therefore, the starting and field rheostats must be suitably interlocked, either mechanically or electrically.

A device of this kind is shown in Fig. 3. The lower row of contacts is connected to the starting resistance, the upper row to the field rheostat. A double lever is provided, the outside arm being for the field contacts, the inside one for the starting contacts (see side view to the right). The outside arm only is provided with an operating handle. In starting, the two arms are moved together, but the field arm is electrically inoperative, because the field current flows directly through the starting-lever, the bar b, the solenoid, and into the field of the motor. At the end of the starting period, the starting-lever is attracted and held by the no-voltage release coil, while the field lever may be moved back to increase the speed of the motor. The upper row of contacts is now operative, since the starting-lever no longer touches the short-circuiting bar b, but rests on the blind button d.

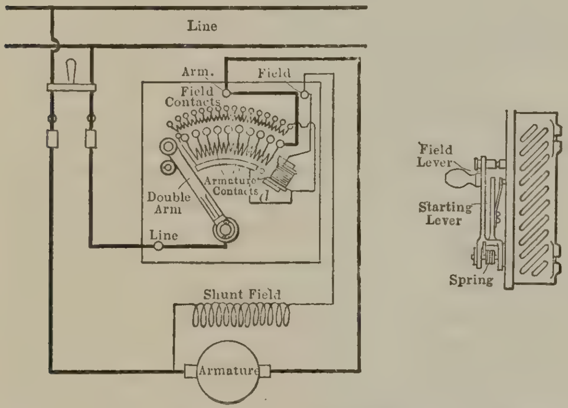

Fig. 3.—Combined Motor, Starter and Speed Regulator.

Opening the main switch releases the starting-lever, which flies back, strikes on its way the field lever, and both levers are returned to the "zero" position. It will be seen from the above description, that it is impossible to start the motor with a weakened field. An overload feature, similar to that in Fig. 2, may be added to this starter.

Order of the Experiment.—(*a*) *Starter with a no-voltage release.*

1. Wire up the motor and the starting-box, and practise starting and stopping. Make clear to yourself the order in which the main switch and the handle of the rheostat must be operated, and to what extent the arrangement is "fool-proof;" also what would happen if the operations are performed in a wrong order.

2. Explain why the handle does not fly back immediately after the main switch is opened; prove the explanation by an experiment. Determine the minimum line voltage at which the coil can hold the arm. Interpose pieces of thin paper between the coil and its armature, and observe the effect on the magnetic attraction.

3. Apply a certain brake load and start the motor by moving the rheostat arm at a certain definite speed, using a metronome. Read the instantaneous values of the line amperes and the volts across the armature every few seconds. With three observers, after some practice, it is possible to take readings on an instrument every two seconds. One man signals at the proper time, another reads aloud the scale indications, the third records the readings. Repeat the same experiment with different rates of starting, and with different values of the load.

4. Measure the total resistance of the starting-box, and the resistances of the separate steps.

This is done by putting a steady current through the rheostat, and taking the voltage drop between adjacent buttons.

(*b*) *Starter with an overload release.*—Two types of starters may be investigated as described above. It is well to test, in addition, an ordinary starter with no-voltage release (Fig. 1), using a separate overload circuit breaker.

1. Connect the devices in succession to a motor, and practise starting. Observe the action of the overload protection. Make clear to yourself that no wrong move is possible, except with deliberate intention.

2. Calibrate the overload attachment in amperes. For this work use an ordinary load rheostat instead of a motor; the main current can be kept more constant.

3. Make tests of the influence of the " time element " on the action of the overload attachment. Adjust a certain current through the overload coil, and then increase the current by a certain per cent, first gradually, then instantaneously, and observe the difference in the operation of the tripping mechanism. Perform this experiment with different values of current, and with different percentages of increase.

4. Compare the action of fuses and of a circuit breaker on slow and sudden overload; obtain, if possible, definite numerical results.

(*c*) *Speed regulator.*—1. Connect the speed regulator to a motor and practise operating it; make clear to yourself the automatic features of the device.

2. Measure the speed and field current of the motor with several positions of the regulating handle.

3. Measure the total resistance of the field rheostat, and the resistances of the separate steps, also the resistance of the motor field.

4. Connect an ordinary motor starter (Fig. 1) and a separate field rheostat in place of the combination starter and regulator. Devise an electrical or a mechanical interlocking arrangement, which would prevent starting the motor with a weakened field.

Report.—1. Make neat sketches indicating the mechanical features and the electrical connections of the devices investigated.

2. Write explicit directions for the operator, and a few warnings as to what not to do.

3. Give the readings of volts, amperes, ohms, speed, seconds, etc., taken during the experiment, and draw your conclusions therefrom.

4. Give your criticisms, favorable or otherwise, of the devices investigated, suggest improvements if any, and some different arrangements which would go around the patents.

ELECTRICAL TESTING

EXPERIMENT E 215-1. WIRING A MACHINE TOOL CONTROLLER

Apparatus.—Experimental, drum-type controller; variable-speed shunt motor; starting rheostat; field rheostat; main ammeter; field ammeter; voltmeter; switch and fuses (or a circuit breaker).

The purpose of the experiment is to familiarize the student with the construction and operation of a machine-tool controller, used in connection with a shunt-wound motor. A machine tool, such as a lathe, if driven by an individual electric motor, usually must be operated within quite a wide range of speeds without changing the gears, and sometimes must be reversed. The motor must be provided with a variable resistance for starting, and also with a field rheostat, if speed adjustment is required; besides, there must be a switch in the main circuit. If it is necessary to operate the motor in both directions, a double-throw switch must be added, so connected that it reverses the current either in the armature alone or in the field only. Sometimes motors are operated on a three-wire system, in which case the connections become still more complicated, especially if the motor must be reversible.

But the use of three or more separate switches and regulating devices cannot be tolerated in practice, this being too awkward and complicated for the operator. It is particularly objectionable in cases where motors are started and reversed many times a day, or are intrusted to persons incompetent in electrical matters, for instance to machine-tool operators. All, or practically all, the necessary switches and rheostats must either be combined into one device, or must be mutually interlocked, so as to make operation in a wrong order impossible. Such a combination apparatus is called a *controller*.

Controller.—The most common form of controller is the drum-type similar to the familiar street-car controller. The wires coming from the line, from the motor and from the starting and regulating resistances, are all connected to stationary controller "fingers," and these are brought into the necessary combinations by the connecting copper pieces, mounted on the revolving drum. The drum is operated by a handle, and in each position of the handle various fingers are connected in a different way, so as to vary the speed of the motor, the direction of rotation, etc.

An ordinary machine-tool controller has, in the most general case, the following three duties to perform: to start the motor, to reverse the motor, and to vary the speed. However complicated the connections inside the controller may be, the machinist does not need to know about them; all he has to do is to turn the handle one way or the other, the controller does the rest.

The elementary controller connections are shown in Figs. 1 to 4. In all these diagrams the controller drum is shown developed on a plane; different positions of the fingers a, b, c, etc., on the copper strips x, y, z, are indicated by dotted vertical lines.

(*a*) *Starting connections* (Fig. 1).—On the first notch the current from one terminal of the line passes through the finger a, the strips z_1, x_4, x_3, x_2, and x_1 to the finger e, thence through the whole starting resistance to the armature of the motor and out to the other terminal of the line. On the second notch the finger d touches the strip x_2, and part of the starting resistance, that between d and e, is cut out. On the third notch still more resistance is cut out, and finally, on the fourth notch, the current flows through a, z, x_4 and b direct to the armature, without any starting resistance in series; this is the running position of the drum.

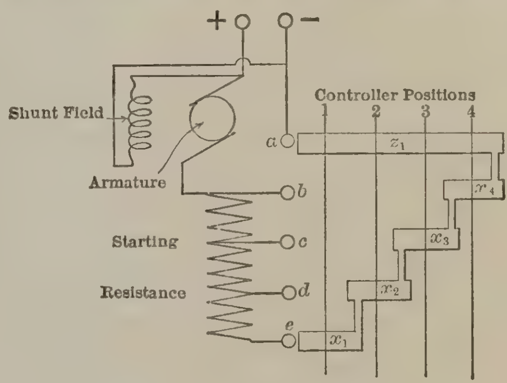

Fig. 1.—Starting Connections.

(*b*) *Speed control by means of a variable resistance in the field circuit* (Fig. 2).—For the sake of clearness the starting connections are omitted. On the fifth notch the field is excited directly across the line, without any resistance in series with it. This gives the strongest field, and therefore the lowest speed. On the sixth notch the resistance between the fingers g and h is inserted into the circuit, on the next notch that between g and i, etc., until on the last notch the whole field resistance is put into the circuit, and the motor runs at its highest speed.

(*c*) *Reversing the motor* (Fig. 3).—When the drum is in the "Forward" position, the current

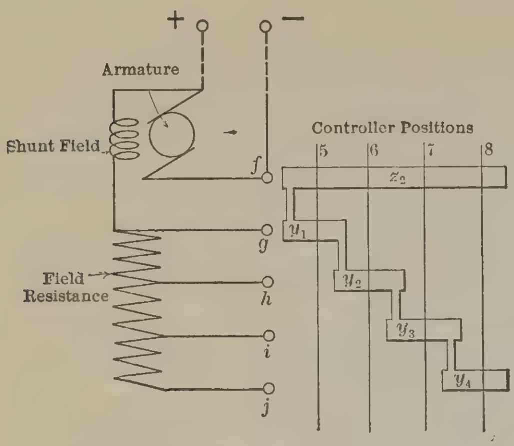

Fig. 2.—Resistance in the Field Circuit.

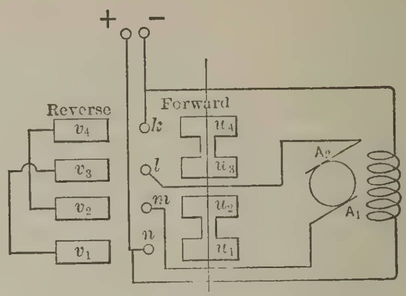

Fig. 3.—Reversing the Motor.

from the positive terminal flows through n, u_1, u_2, and m to the armature terminal A_1, and thence returns to the line through the terminal A_2. When the controller handle is in the "Reverse" position, the current passes through n, v_1, v_3, and l to the armature terminal A_2, thus flowing through the armature in the opposite direction. Therefore, the motor now runs in the opposite direction, the field connections not being reversed.

(*d*) *Speed control by means of a three-wire supply* (Fig. 4).—Assume, for example, that the supply gives 125 volts and 250 volts. In the position marked "Half-speed" the armature is connected between the positive and the neutral (±) wires; at full speed it is connected between the positive and the negative terminals.

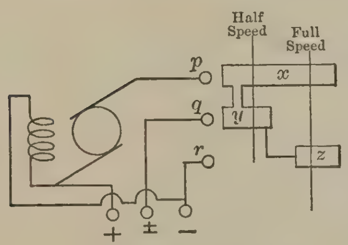

Fig. 4.—Three-wire Supply.

Experimental Controller.—When studying the connections and experimenting with an actual controller, the student is handicapped by the fact that the controller is all wired up, and some of the wiring is not accessible. Moreover, the controller is usually intended for a specific duty only, and cannot very well be used for various purposes.

It is therefore advisable to have in the laboratory an *experimental* controller, especially adapted for exercises in wiring. No permanent connections should be made between the strips on the drum, but each strip should be provided with one or more binding posts so that the student may establish any desired connections himself. Some of the strips must be long, others short, and arranged stepwise, for gradually cutting in or out resistances. Such a controller, if properly designed, is very useful for a study of the operations explained above.

The controller should be mounted horizontally in order to be more accessible, and should have no cover, save that there must be a board on which the fingers are mounted. It is not advisable to have a blow-out coil in connection with it, in order to keep the device as simple as possible. The student should be given an opportunity to study the action of a magnetic blow-out on a separate electromagnet.

Order of the Experiment.—1. Connect up the controller for starting a shunt motor in one direction only, without field control.

2. Add the connections necessary for field control.

3. Supplement the connections by those required for reversing the motor.

4. Wire up the controller complete for running forward and reverse, on a three-wire system.

A shunt motor should be provided, and operated in connection with the controller, this is the best check on the connections. Have an ammeter in the armature circuit, and one in the field circuit; also a voltmeter across the armature terminals. Measure the speed of the motor with various positions of the controller handle.

At the end of the experiment remove all the connections in the controller, so that the next students may have the benefit of designing their own connections.

Report.—Draw a diagram of the actual connections used, combining the developments shown in Figs. 1 to 4. Give the numerical data in regard to the performance of the motor on the different notches.